Chapter 3
Assessing Quality of Viewing Cabinets for Visual Inspection

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Abstract Viewing cabinets provide standard lighting conditions for visual inspection in the color-related industries such as imaging, textiles, and graphic arts. The lighting conditions are typically defined by the correlated color temperature (CCT), distance of departure from the blackbody locus (Duv), color rendering index (CRI), and metamerism index (MI). Various technologies were used to simulate the standard lighting conditions such as fluorescent, tungsten, filtered tungsten, and tunable LED lamps. This paper investigates three cabinets based on different technologies. It showed that all the three cabinets could achieve very high CRI above 95 and small Duv within the tolerance 0.005. A 14-channel LED tunable viewing cabinet performed the most accurate CCT and the best are MI_{vis} and MI_{uv} among all the cabinets tested. Furthermore, it can predict well with lighting parameters across a large range of CCTs.

Keywords LED simulator · CRI · MI · Viewing cabinet

3.1 Introduction

Viewing cabinet is generally used in the color-related industries. For example, in imaging industry, it is frequently used to characterize digital cameras. In the surface color industries such as graphic arts, textiles, coatings, and plastics, it is used for visual inspection to control the color quality. They are built to conform some international standards. For example, ISO 11664-2 [1] defined the spectral power distribution (SPD) of standard illuminants A and D65. ISO 3664 [2] has specified

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the standard viewing conditions for graphic arts by defining correlated color temperature (CCT), Duv, chromaticity coordinates, uniformity, color rendering index (CRI) [3], and metamerism index (MI) [4].

CRI proposed by CIE [3] has been widely used in industry. It describes the color quality of a light source. It can be simply explained as how close the color appearance of a sample viewed between a test source and a reference source, say a phase of daylight. It is first expressed in color difference unit and then transform to a scale-up to 100 (the highest quality).

MI is proposed by the CIE to test the performance of four daylight simulators, i.e. D50, D55, D65, and D75, for which D50 is specifically for graphic art industry. Taking D50 simulator as an example, there are eight specially designed sample pairs (known as metamers), for which each metamer has no color difference under standard CIE D50 illuminant. The color difference of metamer calculated under a particular D50 simulator is used to indicate its quality. The larger difference means the worse performance of this simulator. The eight metamers are divided into two groups: the former five pairs having no optical brightening agent (OBA) and the latter three pairs having OBA. Note that OBA absorbs energy in the UV region and release it in the visible region. The OBA has a large impact on the whiteness perception, which is important for the paper and textile industries. The former are used to test the quality of the visible part of SPD, and the latter are used to test the UV part of SPD. The mean color difference in CIELAB of the former five pairs is termed as MI_{vis}, and that of the latter three pairs is termed as MI_{uv}. The MI (MI_{vis} or MI_{uv}) is graded into five levels: A: <0.25, B:0.25–0.5, C:0.5–1.0, D:1.0–2.0, E: >2.0. Taking critical comparison prints as defined by the ISO 3664, the CCT should be 5000 K, the general CRI (R_a) should be above 90, and the specific CRI (R_i, $i = 1{:}8$) should be above 80. The Duv should be smaller than 0.005 in CIE1976 u'v' diagram. Furthermore, MI_{vis} should be below 1 and MI_{uv} should be below 1.5 in CIELAB color space.

Currently, there are four types of technologies for producing daylight simulators, i.e., florescent tubes, filtered tungsten, filtered Xenon, and tunable LED. Figure 3.1 illustrates the SPDs of these simulators together with the target CIE D65 SPDs. It can be seen that there are many peaks of fluorescent tubes SPD. The CIE D65 SPD is smoother than that of the simulator of fluorescent tube. Therefore, the performance of fluorescent tubes will be rather poorer due to this non-smooth SPD. Filtered tungsten could achieve a much better fit, but its lamp temperature and the voltage should be strictly controlled; otherwise, the SPD and CCT will vary. Filtered Xenon could also simulate the daylight very well while it generates large amounts of heat, which needs to be cooling down. Tunable LED could perform well by combining various narrow-band LEDs covering the whole spectrum range. Moreover, its SPD can be regulated flexibly by controlling the intensity of different LEDs. This advantage makes it attractive allowing tunable LED to simulate various SPDs.

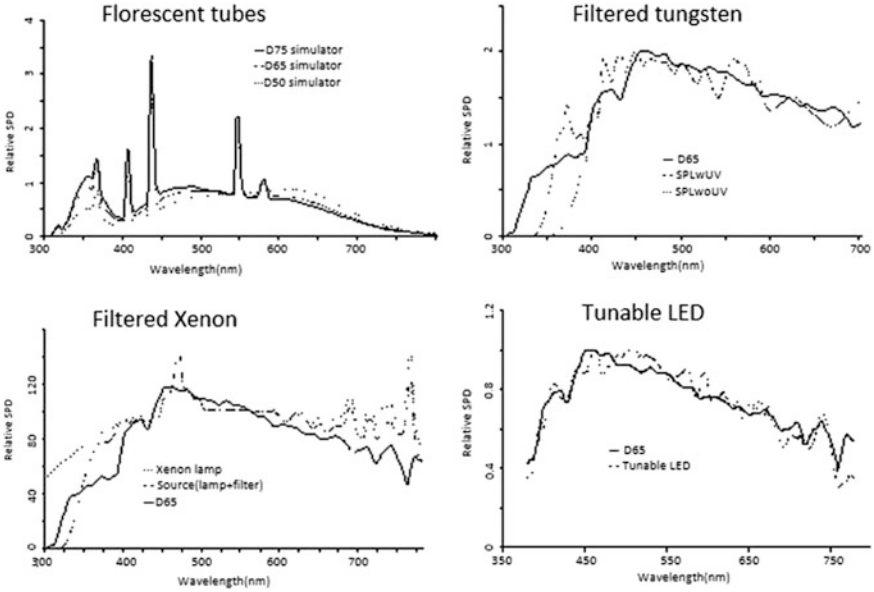

Fig. 3.1 SPDs of various simulators and standard daylight D65

The LED simulator shown in Fig. 3.1 is built by National Institute of Standards and Technology (NIST) [5]. It is an integrating sphere including 33 narrow-band LEDs to simulate target SPDs. However, all the LEDs they used were low power and were a bit weak.

If applying LEDs to viewing cabinet, its power should be high enough to reach certain luminance level. However, there is a lack of commercial high-power LED in the green–yellow range. Generally, wideband white LED is used to cover the green–yellow gap. When simulating some SPDs which have peaks in the green–yellow area, high-power LED could not match the target SPDs very well since there is only wideband white LEDs. Additionally, some types of commercial high-power LED are not as rich as low-power LEDs. Therefore, it is inconvenient to achieve perfect SPD match using high-power LEDs. However, they can achieve high color-quality parameters, e.g. CCT, CRI, and MI. For viewing cabinet manufacturers, they should balance the types of LEDs and lighting quality, the more types of LEDs means the higher cost. As mentioned earlier, some LEDs are more difficult to obtain.

In this paper, three viewing cabinets are compared: a 14-channel LED viewing cabinet, a 5-channel LED viewing cabinet, and a conventional cabinet including a tungsten and two fluorescent lamps.

Fig. 3.2 Typical measuring setup for the evaluation of a viewing cabinet

3.2 The Viewing Cabinets Tested

14 types of LEDs were selected to build the viewing cabinet. Their SPDs covered the near-ultraviolet and visible range, from 360 to 660 nm. Two of them had SPD peaks below 410 nm, two of them were white LEDs, and the others were narrow-band LEDs in the visible range. The power of each LED was about 3 W. Totally 120 LEDs were used. The second simulator only has five LED channels, i.e., one white, one red, one green and two blue LEDs. The conventional viewing cabinet included a tungsten and two fluorescent lamps to simulate CIE illuminant A, D50, and D65, respectively.

Each viewing cabinet was first warmed up to 1 h. Each lamp was measured 8 times over a period of 8 working hours. The measurement was carried out using a JETI 1211 tele-spectroradiometer. It measured the reflected light of 45° from a reference white tile placed in the middle of the bottom of each cabinet. Figure 3.2 shows a typical measuring setup.

3.3 Performance

3.3.1 Comparing Performance Using Color Quality Parameters

The performance of traditional viewing cabinet using a tungsten and a florescent tube, as well as the other two LED cabinets including a 5-channel and a 14-channel LED cabinets, is summarized in Table 3.1. The results are reported in terms of five qualities CCT, Duv, CRI, $MI_{vis,}$ and MI_{uv} for the most commonly used CIE A, D50, and D65 illuminants.

Table 3.1 Comparison between performances of different cabinets

	A	D50	D65
Traditional cabinet			
CCT	2823	4722	6227
Duv	0.004	0.001	0.005
CRI (R_a)	97.9	95.6	97.6
MI_{vis}	n/a	0.81(C)	0.41(B)
MI_{uv}	n/a	3.96(E)	5.70(E)
The 5-LED cabinet			
CCT	2954	5279	6952
Duv	0.004	0.005	0.005
CRI (R_a)	97.9	97.4	96.74
MI-vis	n/a	1.24(D)	1.42(D)
MI-uv	n/a	4.40(E)	6.03(E)
The 14-LED cabinet			
CCT	2879	5021	6475
Duv	0.004	0.001	0.002
CRI (R_a)	97.2	99.4	98.8
MI_{vis}	n/a	0.19(A)	0.24(A)
MI_{uv}	n/a	0.45(B)	0.67(C)

It is shown in Table 3.1 that the 14-channel LED cabinet outperformed the others, i.e., the highest CCT accuracy for each type of illuminant. The other two had small Duv values within the tolerance of ISO3664 (0.005). Additionally, they all achieve very high CRI above 95. In general, the 14-channel LED cabinet performed the best, then the 5-channel LED cabinet, and the traditional cabinet the worst. Finally, there are great differences among them in terms of MI. For D50, the 14-channel cabinet can achieve A and B levels for MI_{vis} and MI_{uv}, respectively, while the traditional cabinet could only reach C and E levels, and the 5-channel LED cabinets are in D and E levels. For D65, the 14-channel cabinet can achieve A and C levels, while the traditional cabinet could only reach BE level and the 5-channel LED cabinet reported DE level.

The overall results showed that the 14-channel LED simulators are performing well. The evidence is shown in Fig. 3.3 which plots the SPDs of the 14-channel LED cabinet and the CIE standard illuminants. Overall, it can be seen that the LED cabinet could simulate the SPDs of standard CIE SPDs well. Most importantly, the simulated SPDs are close to the target SPDs below 700 nm while departs from the target SPDs above 700 nm, since no LED above 700 nm was used. But it can still perform well as shown in Table 3.1.

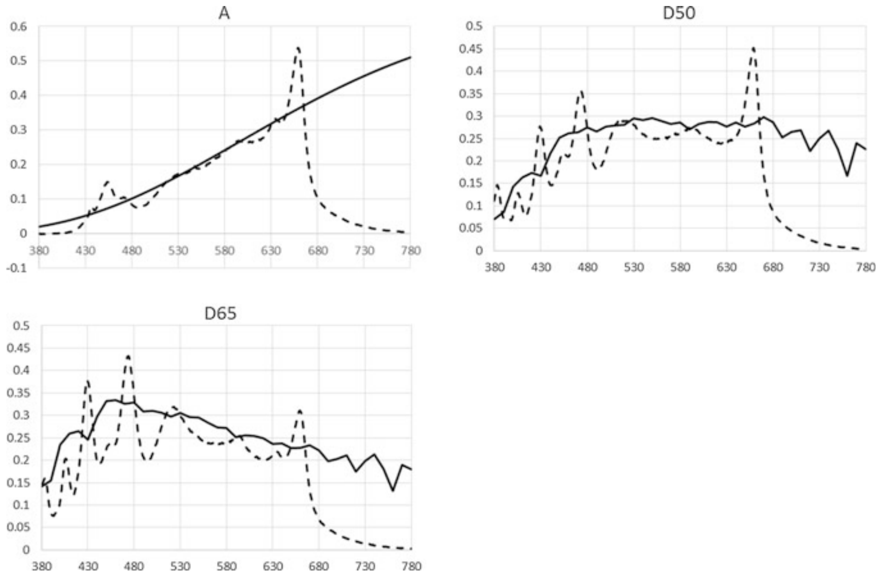

Fig. 3.3 Comparison between SPDs of 14-channel LED cabinet (*dash line*) and the target illuminant (*solid line*)

3.3.2 Reproducing SPDs Under Different CCTs

As mentioned earlier, one important feature of the 14-channel LED cabinet is to realize various target SPDs by regulating the intensity of different LED channels. Four target SPDs are used here as examples. These are: 3000 and 4000 K black body illuminants, and D55 and D75.

Table 3.2 shows the performance of the cabinet and Fig. 3.4 shows the comparison between the target SPDs and the LED-simulated SPDs. It is shown in Table 3.2 that they all could achieve relatively accurate CCT, although D75 simulator has 100 K higher CCT than true D75. Also, they can achieve small Duv within 0.005 units. They all achieve CRI above 95, and 4000 K simulator achieve the highest CRI, 99.1. D55 achieved MI in AB level and D75 in AC level.

Table 3.2 Comparison between performances of different illuminants simulators using 14-channel cabinet

	3000	4000	D55	D75
CCT	3020	4032	5426	7608
Duv	0.002	0.001	0.003	0.002
CRI (R_a)	96.6	99.1	98.9	97.6
MI_{vis}	n/a	n/a	0.14(A)	0.20(A)
MI_{uv}	n/a	n/a	0.48(B)	0.97(C)

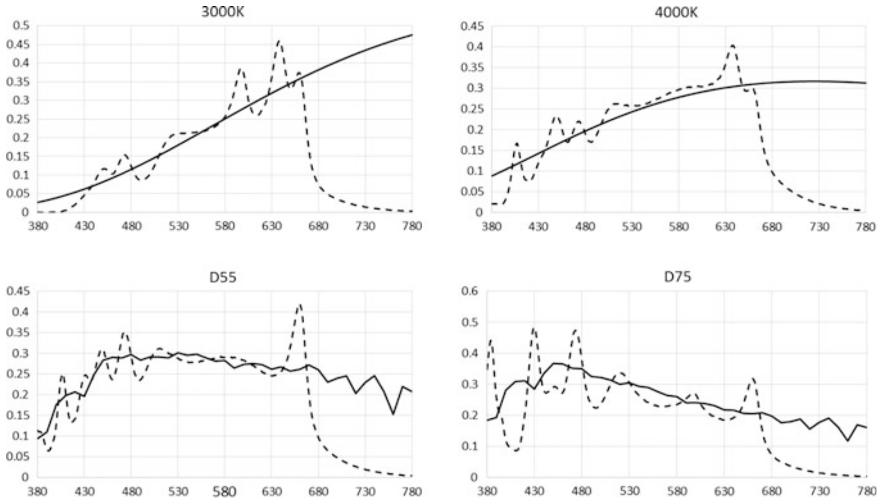

Fig. 3.4 Comparison between SPDs of 14-channel cabinet (*dash line*) and the target illuminants (*solid line*)

3.4 Conclusions

Three viewing cabinets for visual inspection were tested here. The results showed that the 14-channel LED cabinet could achieve high color quality level in terms of CCT, CRI, Duv, and MI. In particular for the latter, it performs much better than the other two, since LEDs used in this cabinet cover not only the visible but also near ultraviolet parts of wavelength range. In summary, the LED Era has arrived in the field of visual inspection. It has the way to be able to tune their intensity to match any desired SPD.

References

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