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# A NOVEL METHOD TO EVALUATE DYNAMIC LIGHTING ENVIRONMENT THAT MEASURES VISUAL AND NONVISUAL PERFORMANCE IN ARCHITECTURE SPACES

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## Abstract

Light and lighting measurements have been out there since the era of Edison bulb. It provides a fair comparison between different products and technologies by quantifying the optical performance to determine its effectiveness in visual performance. In addition, in recent times, the light and lighting experts have continuously found the light contribution to human's non-visual functions such as circadian entrainment, mood regulation, and photobiological and photochemical effects to the retina. More and more lighting products have capabilities to change the lighting condition based on the user's preference. Due to that, the quantification of light and lighting becomes more challenging. In this paper, we focused on evaluating the lighting environment in an architectural space like a classroom or an open office, in which the lighting condition changes throughout the day to provide a useful non-visual stimulus.

*Keywords*: Photometry, Colour Rendering, Dynamic Lighting, Methodology, Nonvisual Performance, Visual Performance, Glare, Photobiological Safety, Circadian

## 1 Background

Over the last few years, with the maturity of solid-state lighting (SSL) products, end-users are looking for more benefits from such products. On the other hand, with the reduction of manufacturing cost, lighting manufacturers have been looking for opportunities to add additional values to such products. These additional values were identified by the fundamental development of the non-visual benefits and risks that different types of light could impact. For example, several studies have shown that the short wavelength (blue near 480 nm) light suppresses human melatonin production in the evening, but improves human's circadian entrainment in the morning [Thapan, 2001; Lockley, 2003, Cajoche 2005]. Other studies have shown very high-power LEDs can potentially damage human's retina under a long exposure time or direct viewing direction. Due to that, several international organizations have provided measurement methods to evaluate the risks [Zheng, 2011; Mou, 2013; Ticleanu, 2015; Behar-Cohen, 2011; Qiao, 2016]. Currently, there is a growing momentum of dynamic LED lighting systems that can change the light level and color over a certain programmed way thus to deliver a more customized solution or provide healthier lighting to space. However, no measurement of photometric, colorimetric characteristics, as well as -opic quantities of the SSL lighting products with dynamic control, have been systematically evaluated and well defined.

## 2 Introduction

In this study, a classroom was selected to test the applicability and effectiveness of the developed methodology. A total of nine SSL, dynamic lighting control fixtures, were installed before the measurement. The dynamic control was programmed into three settings: morning phase, afternoon phase, and evening phase. The original aim of such a system was designed to entrain student's circadian rhythm such that their cognitive function, sleep quality, and concentration can be improved. Furthermore, several China National Regulations and Standardizations on lighting requirements in the classroom were reviewed to ensure the newly installed lighting systems are compatible. The three standards are GB7793-2010 Hygienic standard for daylighting and artificial lighting in middle and elementary school, TJYBZ005—2018 Technical specification for lighting design of classroom in primary & secondary school, and CQC 3155-2016 Energy conservation certification rules for lighting products used in classrooms in schools and kindergartens. The fundamental lighting factors such as the photometric and colorimetric performance are summarized in Table 1.

**Table 1 – Summary of lighting requirement under GB7793-2010, TJYBZ005-2018, and CQC3155-2016**

| Quantities | GB7793-2010 | TJYBZ005—2018 | CQC 3155-2016 |
|---|---|---|---|
| Illuminance (horizontal, desk) | ≥300 lx | ≥300 lx | ≥300 lx |
| Illuminance (blackboard) | ≥500 lx | ≥500 lx | ≥500 lx |
| Illuminance uniformity | ≥0.7(desk)<br>≥0.8(blackboard) | ≥0.7(desk)<br>≥0.8(blackboard) | ≥0.7 |
| CCT | 3300k to 5500k ± 5SDCM | 3300k to 5500k ± 5SDCM | 3500/4000/5000K ± 5SDCM |
| Ra | ≥80 | ≥80 | ≥80 |
| UGR | ≤19 | ≤16 | ≤16 |
| Power density | ≤11W/m$^2$ (at 300lx) | ≤9 W/m$^2$ (at 300lx) | ≤8 W/m$^2$ (at 300lx) |
| Flicker | IEEE PAR1789 | IEEE PAR1789 | IEEE PAR1789 |
| Blue Light Hazard | - | RG0, RG1 | RG0 |

## 3 Measurement methods

For the measurement of dynamic lighting space, the light outputs of the lamps and luminaires in illumination level and spectrum are variable with the time duration and task scenes. We proposed portable measurement devices to measure the integrated lighting effects in a given space. These devices are able to collect the photometric and radiometric quantities over the usage of the space. Unlike conventional measurement, which the measure is less time sensitive, our method that locates the measurement equipment at the architecture space, provides the quantification of the visual and non-visual performance through the entire usage of the space. Here, the measurement devices were used to evaluate the classroom lighting quality with a commercially available dynamic controllable LED lighting system.

## 3.1 Visual performance assessment

### 3.1.1 Illuminance level and uniformity on task plane

The illuminance at the desk and blackboard were measured after the lighting system has been turned on for 15 minutes. Two illuminance orientations were recorded: vertical for blackboard and horizontal for desk. A total of 49 locations were evenly spaced for the horizontal measurement (Table 1), and 30 locations for the vertical measurement was measured on the blackboard surface (Table 2).

**Table 1 – Illuminance distribution on the desk at maximum output （Unit: lx）**

| Output conditions | Illuminance | | | | | | | Results |
|---|---|---|---|---|---|---|---|---|
| CCT= 6500k | 499 | 481 | 523 | 487 | 506 | 518 | 506 | Averaged illuminance 522; |
| | 509 | 513 | 523 | 516 | 507 | 519 | 513 | |
| | 501 | 518 | 511 | 520 | 499 | 510 | 518 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 509 | 513 | 508 | 521 | 511 | 533 | 538 | Uniformity 0.91 |
| | 533 | 538 | 540 | 539 | 541 | 549 | 536 | |
| | 516 | 534 | 541 | 553 | 560 | 564 | 548 | |
| | 520 | 499 | 522 | 523 | 527 | 541 | 527 | |
| CCT= 2700k | 382 | 370 | 410 | 388 | 400 | 405 | 396 | Averaged illuminance 413; Uniformity 0.89 |
| | 410 | 417 | 420 | 406 | 401 | 418 | 409 | |
| | 398 | 408 | 401 | 412 | 398 | 418 | 412 | |
| | 400 | 408 | 400 | 412 | 404 | 421 | 431 | |
| | 420 | 421 | 428 | 420 | 424 | 447 | 425 | |
| | 410 | 430 | 435 | 421 | 434 | 454 | 430 | |
| | 413 | 382 | 418 | 408 | 408 | 424 | 418 | |

**Table 2 – Illuminance distribution on the blackboard at maximum output （Unit: lx）**

| Output conditions | Illuminance | | | | | | | | | | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CCT= 6500k | 632 | 709 | 711 | 721 | 710 | 732 | 720 | 740 | 690 | 660 | Averaged illuminance 683; Uniformity 0.86 |
| | 709 | 753 | 663 | 680 | 693 | 713 | 733 | 772 | 760 | 708 | |
| | 610 | 591 | 614 | 620 | 629 | 630 | 640 | 668 | 650 | 640 | |
| CCT= 2700k | 412 | 501 | 501 | 513 | 500 | 502 | 511 | 523 | 488 | 456 | Averaged illuminance 473; Uniformity 0.84 |
| | 502 | 527 | 453 | 480 | 488 | 493 | 513 | 541 | 520 | 519 | |
| | 412 | 397 | 416 | 416 | 419 | 426 | 431 | 457 | 451 | 439 | |

### 3.1.2 Flicker measurement

In the case of dynamic lighting, the flicker is generally significant in the low illuminance level with low duty ratio for PWM (Pulse Width Modulation) driven light sources. A PMT (Photomultiplier tube)-based flicker photometer with fast response (<1 us), and high sensitivity(0.01lx) is recommended. A TLA-310 flicker photometer provided by SENSING was used to measure the light modulation as a function of frequency as well as the illuminance waveform over time. The measurement recorded the temporal illuminance wave at the task plane. The calculation can be referred to IEEE 1789/IESNA/CIE TN006. An example of the recorded result is shown in Figure 1. In this case, the lighting system tested result is shown in the red dot (1.78 kHz, 57.2%) in the left image, and the illuminance waveform was plotted.

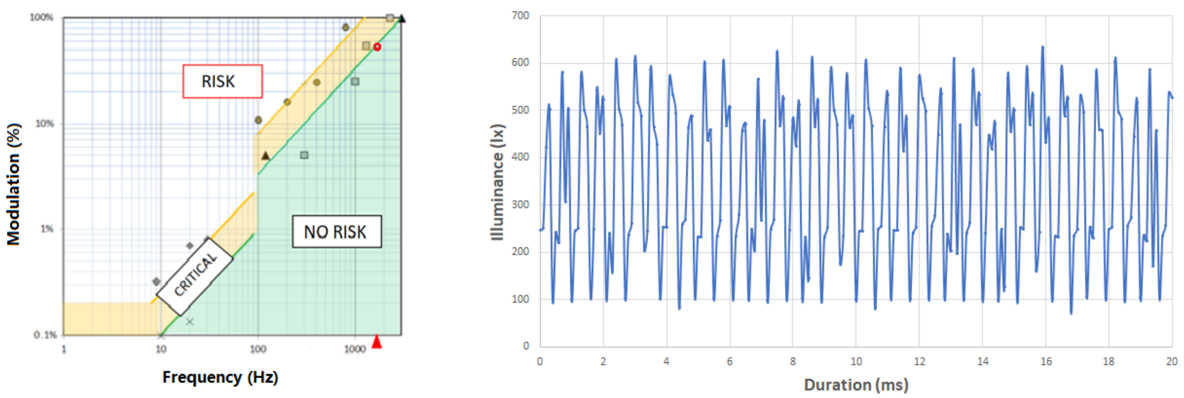


**Figure 1 – An example of flicker measurement**

### 3.1.3 Glare measurement

The glare value is determined at the maximum light output of the luminaires. A spectral imaging luminance meter (MPR-220) that includes a CCD spectroradiometer, 2D imaging photometer and a spatial angular sensor, is applied to measure the luminance profile and position factor of each luminaire, and the background luminance for calculation of glare value (*UGR*=15.6) according to GB7793-2010.

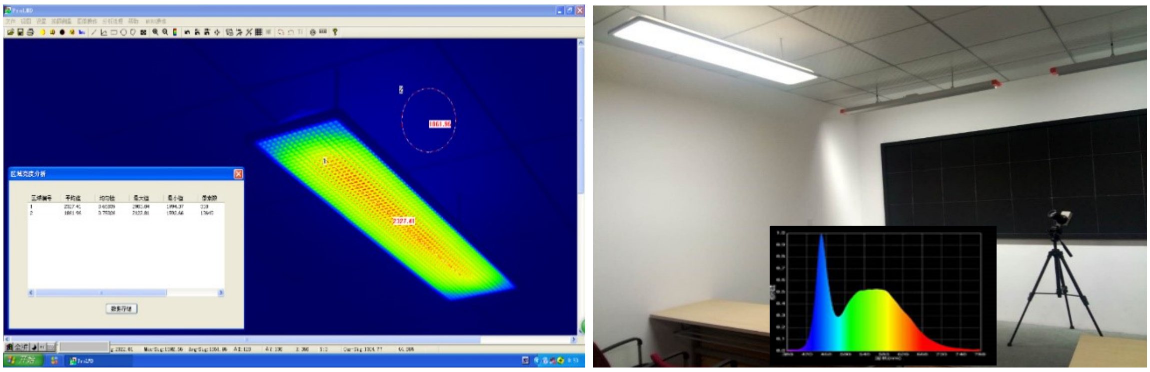

**Figure 2 – An example of glare measurement**

## 3.2 Non-visual performance assessment

### 3.2.1 Photobiological safety evaluation

Currently, IEC TC76 has started in the work of classifying the optical radiation safety on different lighting products. In classroom lighting applications, a few of blackboard lighting luminaires with high intensity and narrow beam profiles is one of the most challenging tasks to achieve high illumination level and uniformity on the blackboard. Thus, array arranged high power LED modules were used in these luminaires. Due to that, such products may often categorize into RG1 (Risk Group 1), or even RG2. Therefore, it is essential to determine the potential hazard. An RMP-200 manufactured by Sensing was used in the measurement. The system has an iris at the front entrance pupil location of the optical imaging lens to create the same optic geometry as the human eye optic. Besides, the iris is set at 7 mm to mimic the eye pupil. It evaluates the blue light hazard within specified FOVs (Mou 2013)

In most general lighting application products, due to the light level requirement is low, most products are categorized under the exempt group (Zheng 2011). In this case, the product is double checked under the risk group classification procedure to demonstrate the evaluation procedure.

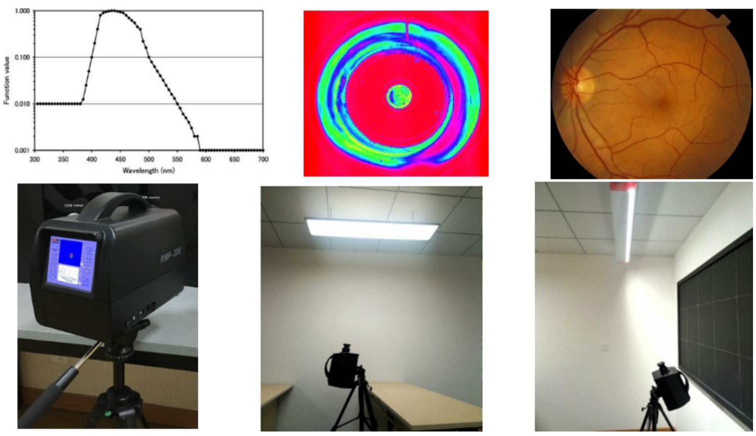


**Figure 3 – An example of the evaluation of photobiological safety**

### 3.2.2 Circadian effects

The measurement determines how much circadian entrainment the eye received during the daytime lighting exposure, or how much melatonin suppression the body received in night time. A pose was attached onto the portable spectro-luxmeter and then mounted onto the student's desk to record spectral irradiance of the illumination continuously. The height was adjusted to match the average height of the students' viewing height (distance between the eye and the table top). The spectrum output in the vertical task plane is important to mimic the human eye location thereby to accurate estimate the number of photons arrive at the retina. In this case, the measurement system adopted the circadian stimulus value [Rea 2011] and α-opic quantity [CIE S026 2018] relating to five photoreceptors to evaluate the entrainment or melatonin production over the course of the day inside the classroom.

There are six different lighting models used in the classroom application, including Circadian lighting, Table lighting, Media lighting, Test lighting, Self-study lighting and Lecture lighting. The circadian lighting is the light output by dynamic adjustment of the lighting system based on the data sheet of circadian 24 hours. The variable quantities of the dynamic lighting were recorded in timing. As an example, the measured horizontal and vertical illuminance levels, and circadian stimulus [Rea 2010] and melanopic irradiance [CIE S026 2018] at vertical plane at three time points of the circadian lighting condition are shown in the Table 3.

**Table 3 – The classroom illumination under the circadian lighting**

| Test Time | 9:00am | 4:00pm | 20:00 |
|---|---|---|---|
| CCT (K) | 5564 | 4228 | 2661 |
| Circadian stimulus (vertical) | 0.478 | 0.242 | 0.104 |
| Melanopic irradiance (vertical) | 0.659 | 0.248 | 0.043 |
| Illuminance (horizontal) | 1212 | 704 | 304 |
| Illuminance (vertical) | 560 | 263 | 81 |

## 4 Summary

Our method provides a better quantification on how dynamic lighting behaves. In addition, that our method provided more useful information on how human received the light stimulus from the environment. The method provides a new way of thinking light and lighting methodology. It provided a starting point to consider the future of light measurement. The portable device can accurately measure the visual and non-visual performance of a dynamic lighting environment in a school classroom and an open office. The market needs to provide guidance on how to measure and report photometric, colorimetric and □-opic quantities. In the future, the time domain shall be also considered.

## 5 Acknowledgment

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