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Fluctuating illuminance pattern of tubular fluorescent daylight in 30-minute versus 8-hour measuring duration

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ABSTRACT

This study aimed to investigate the fluctuating illuminance pattern of tubular fluorescent daylight (CT 6200K). The first investigation focused on the changes within the first 30 minutes in a 1-minute interval while the second investigation examined the changes over 8 hours duration with a 1-hour interval. Luxmeter was used to measure the illumination in pre determined geometrical points in specific room sizes. Illuminance took approximately 5 minutes to reach the peak before it started to deteriorate with time ($r_{s(28)}$ = -0.715, p<0.05). Then, the illuminance seemed to stabilize after the luminaires were turned on for 15 minutes. A similar decreasing pattern was found in the 8-hour duration ($r_{(6)}$ = -0.785, p<0.05) at multiple measurement points ($F_{(1.540,\ 15.398)}$ = 36.804, p<0.05). The recommendation for lighting experiments involving tubular fluorescent light is to start measurement only after the luminaires were turned on for 15 minutes and could be continuously measured for 4 hours.

Keywords: fluctuation; fluorescent; illuminance; light measurement

1. INTRODUCTION

Artificial lighting contributes to the quantity and quality of indoor activities (Norton and Siegwart, 2013). Past research on light and ergonomics emphasized on the quality of the working environment (Boyce et al., 2003; Lee and Moon, 2014; Manav, 2007; Sivaji et al., 2013; Smolders et al., 2012) and learning environment (Mott et al., 2012; Rautkylä et al., 2010; Wessolowski et al., 2014; Winterbottom and Wilkins, 2009). Interior lighting was used to accommodate visual needs, enhance performance, and working ergonomic (Webb, 2006). The lighting requirement for reading and detail demanding visual tasks has been recommended within 100-500 lux (Norton and Siegwart, 2013). Higher illuminance has been associated with alertness and performance (Smolders et al., 2012; Smolders and de Kort, 2014). However, the association between lighting and myopia development remained inconclusive (Ashby et al., 2009; Backhouse et al., 2013; Feldkaemper et al., 1999; Hua et al., 2015; Huang et al., 2009; Karouta and Ashby, 2015; Lan et al., 2014; Norton and Siegwart, 2013; Smith et al., 2012). Lower illuminance was reported to contribute to faster myopia progression (Norton and Siegwart, 2013) while exposure to bright lights for 5 to 10 hours was found to be able to suppress myopia in chickens (Lan et al., 2014) whereas elevating the intensity of laboratory lighting above typical vivarium levels (e.g., 10,000-40,000 vs. 300 lux) inhibited form-deprivation myopia by at least 57% or more in chickens (Ashby et al., 2009; Backhouse et al., 2013; Karouta and Ashby, 2015; Lan et al., 2014). Exposures to outdoors and high-intensity light has been claimed to protect children against myopia (French et al., 2013; Sherwin et al., 2012). To draw more conclusive evidence from lighting and myopia studies, it is imperative to understand what is measured and how to measure them. Guidelines have been developed to facilitate lighting measurement. A measurement is a number assigned to a characteristic of an entity, which can be compared with other entities (Tal, 2017). Measurement accuracy can be evaluated by establishing robustness under various controlled situations representing different measurement variables (Tal, 2017). Lux is the international system of units, or SI-derived unit for illuminance, measuring luminous flux per unit area (Taylor and Thompson, 2008). The unit has been used in photometry as a measure of the intensity, as perceived by the human eye. This study aimed to examine the stability of the instrument indications (lux meter readings of the light source) in illuminance measurement. Light fluctuation and variability issues remained debatable in lighting studies. According to Chartered Institute of Building Services Engineers (CIBSE) & Society of Light and Lighting, the field measurement for artificial lighting requires the elimination of daylight, a minimum of 100 hours lamp used, and the lamp needs to be turned on for at least 20 minutes before any measurement was done (Boyce and Raynham, 2009). However, most studies failed to state any specific time that the luminaires were turned on before any measurement was taken, and the lighting fluctuation was not mentioned throughout the experiments. Different types of lamps have different lamp-life. The light output decreases over time due to various factors such as dust particles trapped in the lamp tube, photochemical degradation, continuous high-temperature operation, and the number of on/off switching operations (Aman et al., 2013). However, the decrement of the light output was reported for long periods of usage while the decrement was rarely studied for shorter periods or on daily basis. The depreciation of the light output of a good operating lamp would be around 5% to 50% from the initial output according to the lamp types (Royer, 2013). The light output could be restored if proper maintenance were carried out. This study was designed to investigate the fluctuation patterns of illuminance measurement within the first 30 minutes and over 8 hours at pre-determined points in specific room sizes. Tubular fluorescent daylight (CCT 6200K) was used as one of the most common light types used in this investigation.

2. MATERIALS AND METHODS

This study was divided into three parts: (1) assessment of the short-duration stability of the illuminance measurement using lux meter in a 30-minute duration; (2) assessment of the long-duration stability of the illuminance measurement; and (3) investigation of the consistency of such measurements in a multiple points setting.

2.1 Illuminance pattern in 1-minute interval for 30 minutes duration

Illuminance measurement for 30 minutes with a 1-minute interval was investigated at the center of a controlled experimental room size of 2 m width x 2 m length x 3 m height space area. The windows and doors were completely closed and darkened to eliminate any light from entering the room from outside. There were four pre-installed luminaires equipped with four Philips Lifemax TLD 18W/54-765 Cool Daylight, 6200K; CRI= 72. A lux meter and mobile stand with marking devices were set up at the measurement point before the luminaires in the room were turned on. All measurements were taken at a height of 0.75 m. The lux meter was zero calibrated and exposed to light outside of the room before the measurement was taken. The illuminance level was recorded at a specific time. The illuminance level was recorded in a 1-minute interval for 30 minutes.

2.2 Illuminance pattern in 1-hour interval 8 hours duration

The same procedure was extended to an 8-hour duration with a 1-hour interval. Overall, the illuminance levels were recorded on the 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, and 8th hours after the luminaires were turned on. The changes in illuminance level over the 8-hour duration in 1-hour interval were also recorded.

2.3 Multiple points illuminance measurements for 8-hour duration

The 8-hour duration with a 1-hour interval was extended to a bigger room size to investigate if there were differences in illuminance changes over multiple measurement points. There were a total of 11 measurement points. This was conducted in an experimental room with a dimension of 4 m width x 3 m length x 3 m height using the same procedures. The changes in illuminance level over 8 hours for all the 11 measurement points were then recorded. The locations of the measurement points are illustrated in Figure 1.

3. RESULTS AND DISCUSSION

3.1 Illuminance pattern in 1-minute interval for 30 minutes duration

The changes in the illuminance level during the first 30 minutes after the luminaires were turned on were summarized and are shown in Figure 2. In the first 4 minutes, the illuminance increased rapidly from 715 lux until it peaked at 979 lux. From there, the illuminance level steadily reduced until it reached 951 lux at the 15th minute. From there onwards, the illuminance seemed to stabilize within ± 2 lux for the next 15 minutes (Spearman's rank-order correlation analysis ($r_{s(28)} = -0.715$, $p<0.05$)).

3.2 Illuminance pattern in 1-hour interval 8 hours duration

The changes in the illuminance level in the 8-hour duration in a 1-hour interval at the center of the room are presented in Figure 3. The highest illuminance level recorded was 953 lux at the 4th hour after the luminaires were turned on; while the lowest illuminance level recorded was 938 lux at the 7th hour after the luminaires were turned on. The difference between the highest and the lowest illuminance level was 15 lux. Illuminance decreased with time over 8 hours duration (Pearson's correlation analysis ($r_{(6)} = -0.785$, $p<0.05$)). The illuminance was stable from the 1st to 4th hour and dropped for about 10 lux at the 5th hour and remained stable until the 8th hour.

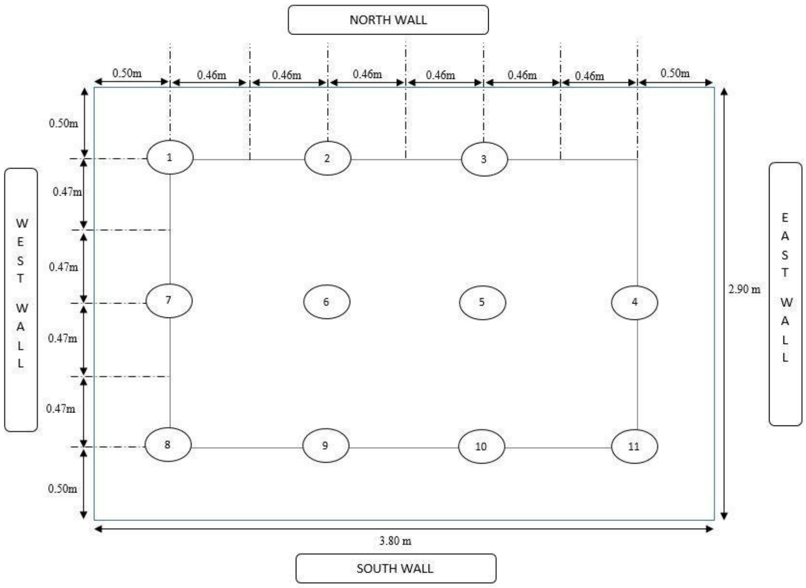

Figure 1. Illustration of the 11 measurement points in 4x3x3 m^3 room size

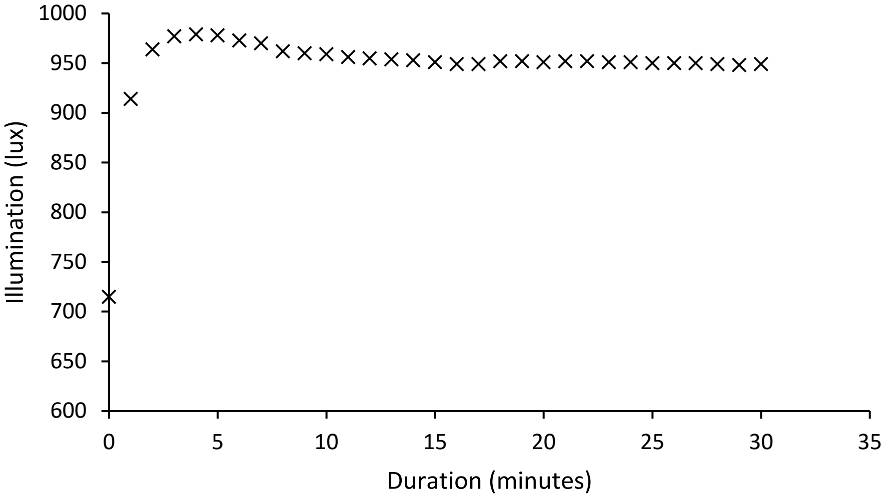

Figure 2. Illuminance level in 30-minute duration with a 1-minute interval at one point

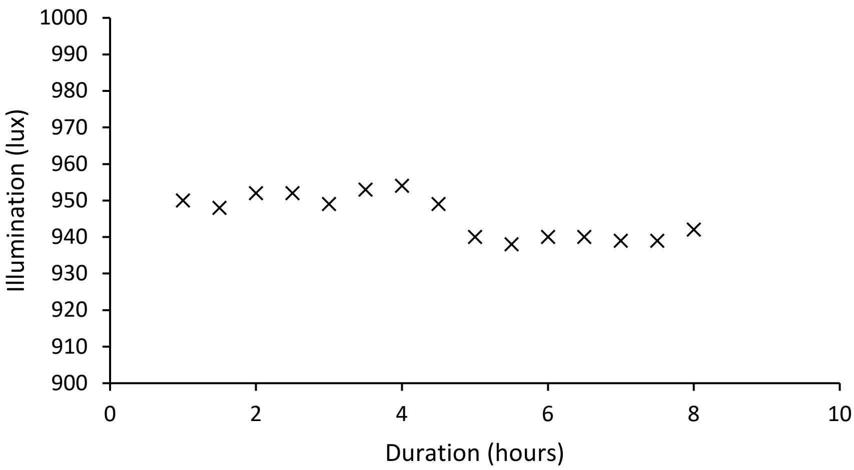

Figure 3. Illuminance level in 8-hour duration with 1-hour interval at one point

3.3 Multiple points illuminance measurements for 8-hour duration

Illuminance measurement in the 8-hour duration with 1-hour interval was then extended to a bigger room size. Illuminance levels at multiple points were measured to investigate the consistency in illuminance across the entire space. The measurements were taken simultaneously at one point after the other. The first set of measurements took place 1 hour after the luminaires were turned on. All illuminance levels were recorded and are shown in Table 1. The average, minimum, and maximum values for each measurement points were summarized and presented in Table 2. There were statistically significant changes in illuminance with time over 8 hours (one-way repeated measures ANOVA: $F_{(1.540,\ 15.398)} = 36.804$, $p<0.05$). The highest mean illuminance level was at the 4th hour (719.9 ± 136.3 lux) while the lowest mean illuminance level was at the 7th hour (708.1 ± 134.6 lux).

Table 1. Summary of illuminance measurements for 11 points in 8 hours

Time (hour) lamp was turned on (total 8 hours)	Illuminance level on the measurement points (lux)										
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
1	611	763	715	553	880	950	750	635	790	743	494
2	613	763	715	555	880	952	751	637	793	748	496
3	616	768	722	554	880	949	749	636	790	746	496
4	615	767	720	556	884	954	752	637	792	746	496
5	609	756	711	551	872	940	740	628	782	737	491
6	605	751	703	546	870	940	743	634	788	740	487
7	603	749	700	544	867	939	741	633	787	739	487
8	605	752	704	547	870	942	743	634	789	741	491

Table 2. Minimum, maximum, and average illuminance for eleven measurement points

Illuminance level (lux)	Measurement point										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Average	609	758	711	551	875	946	746	634	789	742	492
Minimum	601	748	700	544	867	938	740	628	782	737	487
Maximum	616	768	722	557	884	954	752	638	793	748	497
Differences	15	20	22	13	17	16	12	10	11	11	10

According to the guideline by CIBSE & Society of Light and Lighting, lighting installation using discharge lamps such as fluorescent lamps required a minimum of 20 minutes to stabilize the light output (Boyce and Raynham, 2009). Our findings supported the recommendation in which 15 minutes was sufficient. After 15 minutes, the illuminance only changed for ± 2 lux, which might be due to instrument improbability of about ± 4% or ± 6% depending on the type of the lux meter (Boyce and Raynham, 2009). The illuminance stability sustained for 4 hours before it reduced on the 5th hour and maintained in the same range until the 8th hour during the 8-hour duration investigation. The changes in illuminance were consistent with multiple points in the room. The small reduction in illuminance might be due to various reasons such as lamp and ballast failure, lamp lumen depreciation, luminaire dirt depreciation, and room surface dirt depreciation after thousands of hours of luminaires operation (Aman et al., 2013; Boyce and Raynham, 2009; Royer, 2013). The improper light output might induce erroneous measurement in the light investigation of myopia development or visual ergonomic studies. It is important to accurately measure the light output in a consistent manner in order to draw any conclusive evidence. Myopia has been indicated to progress if the reduction of illuminance reached a critical point. Reduction by 10 to 20 lux from the 5th to the 8th hour of the lamp operational time was found in this study. The light output of artificial light sources depreciated over time (Aman et al., 2013; Royer, 2013). Minor changes in illuminance were found to affect subjective visual performance and visual fatigue when using a visual display unit (VDU). Higher illuminance led to faster character-search time and reduced visual fatigue among subjects using electronic paper display (Lin et al., 2011). This was more apparent under ambient lighting conditions with illuminance levels ranging from about 30 to 90 lux. It was unclear whether a similar outcome might occur under brighter lighting conditions. This study showed that the illuminance level remained stable for 4 hours before it reduced slightly to about 10 to 20 lux in the next 4 hours. Depreciation was recorded after long periods of usage from a minimum of 750 up to 50000 hours (Aman et al., 2013; Royer, 2013). The study revealed that the light output could not remain the same for 8 hours of continuous usage.

A variety of conceptual, metaphysical, semantic, and epistemological issues has constantly been related to measurement. Mathematical theories of measurement addresses the mathematical foundations of measurement scales (Tal, 2017). Operationalism and conventionalism were primarily concerned with the semantics of quantity terms. Realism is concerned with the metaphysical status of measurable quantities. Information-theoretic and model-based accounts are concerned with the epistemological aspects of measuring (Tal, 2017). Our findings stressed the importance of relating these principles to ensure consistency with each other. High-energy consumption in a building leads to the utilization of daylight with a lighting control system to light the spaces to save energy (Lim and Ahmad, 2013; Roisin et al., 2008). Daylight can minimize lighting operating cost. Its limitations include dependency on the availability of sunlight, weather, night-time, and the design of the building (Boyce and Raynham, 2009). Therefore, a welloptimized independent artificial lighting system might be needed to light the spaces when daylight was not available. The artificial lighting system design process has been made easier in the modern day with various technological tools available to aid lighting and interior designers. Lighting simulation tool such as Relux was used to visualize the illuminance condition in the room before the luminaires were installed (Madias et al., 2016; Yu et al., 2014). A psycho-visual experiment method with a virtual reality stereoscopic display was used where the scene was modelled with the 3DS MAX software (Villa and Labayrade, 2013). Simulation tools might help to visualize the lighting condition in the room, but field measurement remained essential to ensure that the lighting installed was functioning as intended. Indications in numbers describe the situation of the instrument (lux meter) and this should not be confused with the measurement outcomes (internal space lighting analysis) that relates to the situation being measured. This study only reported one aspect of the indications. Our current findings accomplished its goal to systematize the measuring instrument to be used in an internal space lighting application. Applications might contain measurement values assigned to models (predicting model for functional internal space lighting) based on instrument indications (readings in lux meter). Measurement outcomes could involve statistical analysis of multiple indications. The same indication might be applied differently depending on the environmental influences. Measurement outcomes integrate the adjustments based on theoretical assumptions of the instrument and its interactions with others. Further investigation on lighting measurement is essential for a better understanding of our artificial lighting system and its influence on the quality of life.

4. CONCLUSION

The fluctuating illuminance pattern of tubular fluorescent daylight was apparent in both the 30-minute and 8-hour measuring duration explorations. The illuminance level can be measured from 15 minutes onwards, which was 5 minutes earlier than the guideline recommendation and can be continuously measured up to 4 hours after the luminaires were turned on. The consistency was unveiled in multiple points of investigation. Previous studies on illumination measurements were usually executed on a single plane. Similar multiple points of investigation can be expanded to other types and models of lighting. In any future research concerning artificial lights such as color perception, visual stress, visual behavior, or refractive development investigation, it would be best to do experiment between 15 minutes and 4 hours after the luminaires are turned on to minimize the fluctuation of illumination.

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