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The Effect of Illuminance and Color Temperature of LED Lighting on Occupants' Perception and HRV

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ABSTRACT

Purpose: It is crucially important that indoor luminous conditions of built environments be carefully studied so as to promote comfort and occupants' well-being. Method: The current study therefore focuses on the lit aspect of an enclosed space considered to be a resting room (4.5 m X 6.32 m X2.5 m). Particularly, on the effect that light levels and light color temperatures have on the physiological and psychological responses of resting occupants. To do so, a questionnaire survey was carried out on 50 subjects. The independent variables for the experiment included 9 different luminous environment conditions setup using 3 different levels of illuminance (50 lx, 150 lx, 300 lx) and 3 different color temperatures (2000 K, 3800 K, 5600 K). A questionnaire was utilized in determining which conditions were preferred by occupants. Result: As it turns out, indoor luminous environment designed for relaxation purposes should display luminance levels of at least 150 lx and 3800 K of color temperature in order to provide a visually comfortable environment suitable for the occupant's relaxation while at the same time promoting the psychological and HRV well-being of resting occupants. ⓒ 2015 KIEAE Journal

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1. Introduction

1.1. Research background and objectives

With the developments in LED lighting recently, shift from prior lighting towards LED lighting is being done fast. It is because LED lighting has lower power consumption by 20%~70% than fluorescent lamp with life span 5 times longer (fifty thousand hours), and it has also low possibility to be damaged compared to light bulb which uses glass thus lowers much cost in maintenance management such as repair or replacement. With this advancement in lighting technology, traditional lighting market is rapidly changed into LED lighting market helping us expect that 30% of current lighting would be replaced with LED lighting within 2015. One advantage of LED lighting is that it can realize the light in widespread wavelength that includes visible rays freely. This advantage means it can be utilized as emotional or well-being lighting that affects invisible or visible aspects of human by using the light in various ways not being limited to glowing the light simply.

Smart LED lighting was created grafting LED lighting and object Internet technology that links and shares sensor information of objects connected through Internet with nearby devices and people. Unlike prior lighting always fixed, Smart LED lighting enables control over color, brightness users demand possessing variability and availability towards new environment any time.

We perform various tasks indoor with the objectives of various visual works such as rest, talk, reading, watching TV, computer work and the work done continuously and needed whatsoever is rest. Resting is a very important work because it relaxes the body and the mind of occupants. Since this work is done in various indoor setting such as houses and offices, flexible lighting environment design is needed to satisfy occupants along with various works.

This research composed lighting environment condition of resting space combining illuminance and color temperature using LED lighting. We would like to analyze the changes in psychological state and lighting quality that occupants perceive according to the condition of lighting environment through survey then present design conditions for lighting environment of resting space for physical and psychological health of occupants by evaluating physiological reaction through measurements of HRV.

1.2. Literature review on effect of illuminance and color temperature of LED lighting on occupants

As a result of literature review of Yoon, Kyu-Hyun(2014), Kim, Su-Yeon(2013), Park, Hun-Su and 3 others(2012), No, Jung-Rim

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(2011), Hwang, Tae-Yeon and 2 others(2011), Ji, Sun-Duk and 3 others(2006) as prior researches about the effect of illuminance and color temperature of LED lighting on psychology of occupants, illuminance range suitable for resting was proposed to be between 85 lx and 300 lx and color temperature was from 3000 K to 5000 K. Preference between 150 lx and 200 lx was shown most positively and warm lighting with low color temperature (below 2700 K) was evaluated to give comfort. Advanced researches were all evaluated through survey method and most of items in the survey were evaluated vocabulary such as comfort, preferred, pleasant with 5 to 7 points criterion to evaluate comfort, preferred, pleasantness. This research evaluated changes in perception of lighting quality through total 11 adjective vocabularies with 5 adjective vocabulary about perception on lighting intensity, 4 vocabularies on comfort perception, 1 on pleasantness and intends to evaluate in-depth psychological change rather than simple lower measure vocabulary test applied in advanced research through comparative evaluation survey of mood.

As a result of literature review of Jun, Woo-Suk and 3 others (2007) as advanced researches on effect of illuminance and color temperature of LED lighting on the physiology of occupants, HRV that measured changes in automatic nervous system showed low activation in parasymsympathetic nerve in warm lighting and high one in cool lighting. This research measured HRV according to the color change of lighting, not color temperature and illuminance, and expects different result from LED lighting that intends to evaluate in this result using halogen color filter, not LED as lighting as well. Also, it evaluates changes in automatic nervous system depending on the changes of illuminance and color temperature and in-depth physiological change on occupants more than advanced researches did by analyzing changes in mean and standard deviation in pulse and ratio of symsympathetic and parasymsympathetic nerve not to mention parasymsympathetic activation and symsympathetic activation.

2. Research method

2.1. Organization of laboratory for lighting environment evaluation

Psychological, physiological reaction laboratory of K university was organized into resting place as laboratory to propose resting place design conditions for physical and psychological health by evaluating changes in automatic nervous system activation, mood, perception of indoor lighting of occupants regarding indoor lighting environment organized of LED lighting. Laboratory is composed of 4.5 m (W) x 6.2 m (L) x 2.5 m (H) like Figure 3 and 4 and just like Figure 2, every indoor opening is closed with black

Fig. 1. Smart LED lamp and lighting fixture

Fig. 2. Laboratory for Psychological reaction assessment

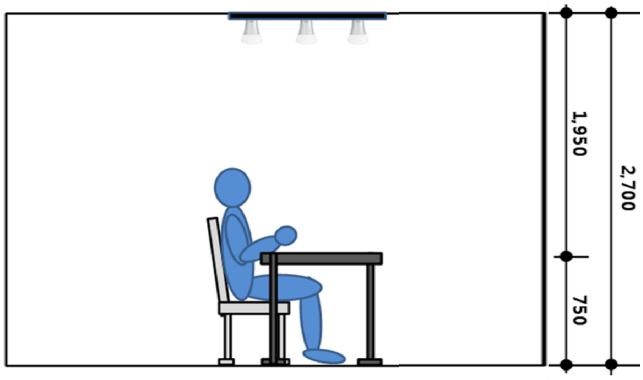

Fig. 3. section of psychological reaction laboratory

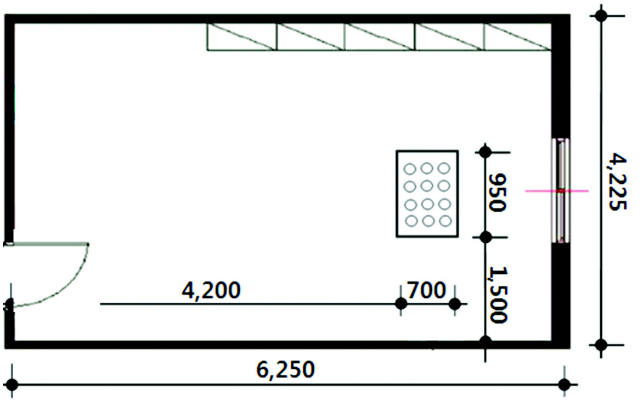

Fig. 4. plan of psychological reaction laboratory

curtain and blind to block the outside light and nearby environment is controlled so that no foreign noise can be heard.

Like Figure 1, LED lighting is an overall lighting method that lights the whole room with the ceiling light and the subject did HRV measurement and survey located below the light. To realize resting place, sofa, table, bookshelves are allocated with indoor all painted with white paint. There are books in various colors inside the bookshelves and the height of the ceiling is 2.7 m. The size of the table is 1.5 m (L) x 0.5 m (W).

Lighting device is composed of 12 HUE, Smart LED lighting of Phillips company on 12 lighting devices in the size of 0.95 m (L) x 0.7 m (W). Smart LED lighting HUE can express more than 16,000,000 colors. Moreover, it can be on/off automatically at the time set by users and enables free direction of brightness, color that lighting users want. To organize lighting environment conditions, application that could save illuminance and color temperature case was used.

2.2. Experiment condition and evaluation method

Conditions of laboratory lighting environment are realized with illuminance and color temperature and they were contemplated on illuminance conditions presented in JIS of Japan, IESNA lighting Handbook of USA, KS of South Korea like <Table 1-3>. Illuminance standard by room where occupants mainly rest was examined and living room in house was between 30 lx to 60 lx, bedroom was between 15 lx to 50 lx, office lounge was from 60 lx to 100 lx, hospital ward was between 50 lx to 300 lx. The standard of space where resting is done is between 15 lx to 300 lx, so illuminance conditions were classified into 3, 50 lx. 150 lx, 300 lx within this range.

Table 1. KS A 3011 Illuminance standard

KS A 3011		minimum (lx)	standard (lx)	maximum (lx)
dwelling	living room	30	40	60
	bed room	15	20	30
office	rest room	60	100	150
hospital	patient's room	150	200	300

Table 2. IESNA Lighting Handbook 10th Edition Illuminance standard

IESNA Illuminance standard		horizontal illumination(lx)	Vertical illuminance(lx)
Residences	Livingroom	30	30
	Bed room	50	30
Office	Break room	100	30
Hospitality	Patient room	50	20

Table 3. JIS General rules of recommended lighting levels

JIS Z 9110:2010		Maintained illuminance(lx)
Residents	Living room	50
	Bed room	20
Office	Resting room	100
Healthcare facilities	Ward	100

Table 4. Indoor environment condition

lighting environment condition		Illuminance (lx)		
		50	150	300
Color temperature(K)	2000	condition 1	condition 4	condition 7
	3800	condition 2	condition 5	condition 8
	5600	condition 3	condition 6	condition 9

Kim, Su-Yeon(2013) examined physical quantity of lighting in 18 model houses in Seoul and Kyunggi region and as a result, there was no trend by space type in case of color temperature but they could be divided into three groups. below 3000K, from 3000 K to 4000 K, more than 4000 K. No place used only constant color temperature by space type and it can be seen that various color temperature is used in the space because there is no recommendation standard for color temperature according to the space. Thus, among three groups that are below 3000 K, from 3000 K to 4000 K, more than 4000 K used the most, 2000 K as warm lighting, 3800 K as medium lighting, 5600 K as cool lighting were selected. <Table 4> shows 9 lighting environment conditions putting illuminance (50 lx, 150 lx, 300 lx) and color temperature (2000 K, 3800 K, 5600 K) together and experiment condition was organized in random order so that subject cannot expect next order.

Evaluation method is divided into subjective evaluation and physiological measurement according to the conditions of lighting environment. Subjective evaluation is done through mood survey and perception survey regarding indoor lighting quality, physiological measurement is done through HRV measurement.

3. Methodology

3.1. Perception survey on indoor lighting quality

Perception survey of indoor lighting quality is evaluated with 7-point criterion and is a meaningful criterion about 10 vocabularies. This vocabularies were re-organized so that subjects can more easily understand after translating English vocabularies used in the research of Kuller & Wetterberg (1993,1996), prior researchers, into Korean. M.Johansson et al.(2013) divided 10 vocabularies into 3 groups, perception on lighting intensity, comfort perception, pleasantness perception.

Profile of mood states

Profile of mood states is developed by McNair DM et al.(1992). This test can be divided into 6 subgroups that are nervousness-anxiety, depression - disappointment, fury − aggression, vitality-vigor, fatigue-lethargy, confusion-embarrassment. Evaluation

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items are composed of total 65 items that are 9 nervousness items, 15 depression items, 12 fury items, 8 vitality items, 7 fatigue items, 7 confusion items, 7 pile items. To convey more exact meaning of English evaluation vocabularies, they were translated into Korean and evaluation paper was re-organized. Each item was made to be evaluated in self-report means with 5-point criterion from not at all(0) to Yes, very much(4).

3.2. HRV measurement

Physiological measurement measured HRV to evaluate changes in activation of automatic nervous system of subjects depending on the changes in lighting environment. HRV was measured using uBioMacpa pulse measuring device of bio sense creative company. This device measures pulse in the way that changes in aorta pressure is transferred to periphery arteriole upon supply of blood towards the whole body through aorta whenever heart contracts. Pulse wave expresses changes in conveyed vascular dimension in wavy pattern. This device measures pulse change with noninvasive measures putting index finger of subject to this device and analyzes standard deviation in pulse, average deviation in pulse, ratio of sympathetic and parasympathetic, activation of parasympathetic, sympathetic activation from software of relevant device.

Sympathetic activation shows high figure in nervous and excited state and parasympathetic activation is shown high in relaxed state such as enough rest and low in angry, worried, scared state. Ratio or parasympathetic and sympathetic show the ratio of activation of sympathetic and parasympathetic showing immunity index. Standard deviation in pulse shows adaptability of body and is better the higher, showing adaptability towards stress. Average deviation in pulse is an index that shows stability of heart function and is shown low in angry, worried, scared state.

3.3. Experiment process and subject composition

The experiment lasted for 5 weeks from Oct, 14, 2014 to Nov, 21, 2014. Subjects were undergraduates and graduates with various majors of K university at the age of 23.6 on average, subjective measurement was done targeting 50 subjects (50 males, 50 females) physiological measurement was done targeting 36 subjects who answered there is low physical fatigue thanks to enough rest and sleep on the measurement day among 50 subjects who participated in subjective measurement (18 males, 18 females).

Subjective measurement was done when subjects were made to stare the front sitting in the middle of the laboratory. After adjusting to the dark room turning all the indoor lightings off for 3 minutes before applying each lighting condition, the condition was applied and survey was done under it after adjusting to lighting condition. The experiment was repeated 9 times, spending approximately 80 minutes.

Physiological measurement was done supposing subjects are doing resting work in comfortable state sitting on the sofa in the laboratory and the measurement was done when the subject was in stable state after adjusting to the room resting in the laboratory for about 10 minutes. In compliance state to dark room for 2 and a half minutes, pulse change was measured then repeated after adjusting to the lighting condition for 2 and a half minutes again thus to statistically analyze the increase in automatic nervous system when dark room is changed into lighting condition. 5 minutes was taken for 1 time measurement, so about 45 minutes was consumed in total for total 9 sessions.

3.4. Data analysis method

Using SPSS Ver.21, dual variance analysis of effect test of interaction (Two-way ANOVA) was done to examine the changes in variables as a result of following the level change in illuminance and color temperature to independent treatment variables and since there are two treatment variables, they were applied to examine the treatment effect. To test if the effect of changes in illuminance on result variables is different according to the level of color temperature, interaction effect was tested. We could check the significance in significance probability 95% and post-mortem - dual analysis method used Scheffe law.

Effect test between entity induced effect size through partial eta squared. In variance analysis, effect size is a standard value that shows average difference between groups so it is considered that the effect size is small if partial eta squared value is lower than 0.01 for it is the value that determines the effect size in dual analysis and middle if 0.06, big if higher than 0.14. We confirmed average difference of dependent variables through this partial eta squared value.

4. Subjective evaluation that LED lighting has on lighting perception

4.1. Quality evaluation of indoor lighting

<Table 5> is the result of statistic analysis regarding perception change in indoor lighting by illuminance. Perception of lighting intensity was positive in order of 300 lx > 150 lx > 50 lx and comfort perception was positive as well in order of 150 lx > 300 lx > 50 lx , pleasantness perception was positive too in order of 300 lx > 150 lx > 50 lx.

When comparing effect size through partial eta squared value among items that showed meaningful difference according to the illuminance, partial eta squared value was shown big, more than

Table 5. Perceived indoor lighting quality Two-way ANOVA analysis result

assessment	classification	DV(1)	source	p(3)	η(4)
Perceived indoor lighting quality	Perceived lighting strength quality	clear delicate	Illuminance	.000	.453
			CT(2)	.000	.259
			Illuminance * CT	.000	.159
		weakness strong	Illuminance	.000	.387
			CT	.000	.117
			Illuminance * CT	.000	.105
		bright dark	Illuminance	.000	.621
			CT	.000	.076
			Illuminance * CT	.000	.079
		clean dull	Illuminance	.000	.136
			CT	.540	.003
			Illuminance * CT	.001	.043
		distinct cloudy	Illuminance	.000	.507
			CT	.000	.099
			Illuminance * CT	.000	.133
	Perceived comfort quality	rough soft	Illuminance	.000	.051
			CT	.000	.097
			Illuminance * CT	.015	.028
		warm cool	Illuminance	.000	.037
			CT	.000	.517
			Illuminance * CT	.038	.023
		natural unnatural	Illuminance	.000	.086
			CT	.000	.037
			Illuminance * CT	.003	.036
		no glare glare	Illuminance	.000	.175
			CT	.000	.037
			Illuminance * CT	.063	.020
	Perceived amenity	pleasant unpleasant	Illuminance	.000	.319
			CT	.000	.074
			Illuminance * CT	.000	.080

(1) dependent variable (2) color temperature (3) significant < 0.05
(4) Partial Eta Squared

0.14, in perception of lighting intensity 'clear-soft', 'strong-weak', 'bright-dark', 'clear-dim', in comfort perception 'soft-rough', 'not dazzling-dazzling', and in pleasantness perception 'pleasant-unpleasant'. It is decided that 7 items above show sensitive reaction according to relative illuminance.

In perception change of indoor lighting quality according to the color temperature, perception of lighting intensity was shown the most positive in 5600K and comfort perception in 3800K, pleasantness perception in 5600K. It was shown that perception on lighting intensity and pleasantness are more positive as s illuminance and color temperature become higher, and that people perceive the most comfortable state in illuminance 150 lx and color temperature 3800K.

When comparing effect size through partial eta squared value among items that showed meaningful difference according to color temperature, partial eta squared value was shown higher than 0.14 in 'clear-soft' of perception on lighting intensity and 'soft-rough' , 'warm-cold' of comfort perception. 3 items above are determined to have sensitive reaction according to the relative color temperature. It is judged that 'clear-soft' and 'soft-rough' items are the ones that react the most sensitively according to the illuminance and color temperature change in perception of lighting quality for partial eta squared value of those in illuminance and color temperature were all shown high.

4.2. Result from profile of mood states

<Table 6> is the result of statistical analysis regarding mood change by illuminance. Mood change by illuminance showed meaningful difference in every 6 items that are 'nervousness', 'depression', 'fury', 'vitality', 'fatigue', 'confusion' and also positive as they became lower which are negative feelings as illuminance increases. But in case of vitality which is a positive mood, it was shown to decrease as illuminance increases, rather. Mood change by color temperature showed meaningful difference only in vitality and confusion but that is judged not to have much effect since it was shown really small compared to changes by illuminance.

Among items that showed statistically meaningful difference by illuminance and color temperature, partial eta squared value in 'depression', 'vitality', 'fatigue', 'confusion' items were shown higher than 0.14 with big effect size thus showing big average difference by illuminance in above items. Thus, 'vitality', 'fatigue', 'confusion' emotion rather than 'nervousness', 'fury' are judged to be more sensitive by illuminance. Items that showed meaningful difference by color temperature all showed small effect size.

Correlation between illuminance and color temperature about mood showed meaningful difference in 'vitality', 'fatigue', 'confusion' state and positive mood was shown as illuminance level by each color temperature gets higher. Thus, mood was shown more positive as illuminance level gets higher (300 lx > 150 lx >50 lx) and there was no big difference in mood by color temperature.

Table 6. Mood stats Two-way ANOVA analysis result

assessment	DV	source	p<0.05	η
Profile of mood stats	tension	Illuminance	.034	.015
		CT	.188	.008
		Illuminance * CT	.698	.005
	gloom	Illuminance	.000	.192
		CT	.349	.005
		Illuminance * CT	.002	.037
	anger	Illuminance	.000	.099
		CT	.850	.001
		Illuminance * CT	.111	.017
	vitality	Illuminance	.000	.189
		CT	.031	.016
		Illuminance * CT	.000	.051
	tiredness	Illuminance	.000	.184
		CT	.097	.011
		Illuminance * CT	.000	.064
	confusion	Illuminance	.000	.167
		CT	.052	.013
		Illuminance * CT	.008	.030

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5. HRV reaction of occupants by LED lighting change

<Table 7> is the result of statistical analysis on automatic nervous system change as a result of HRV measurement. LF refers to sympathetic activation, HF to parasympathetic activation, LF/HF to ratio of sympathetic to parasympathetic. SDNN to standard deviation of pulse, RMSSD to average deviation of pulse. 'sympathetic activation' is shown to have meaningful difference by illuminance. 'sympathetic activation' shows more activation as illuminance gets higher. Since 'sympathetic activation' is more activated in nervous, excited state, we can say that those state are lowered as illuminance got higher. (300 lx > 150 lx > 50 lx) 'Pulse average deviation' showed statistically meaningful difference by color temperature. 'Pulse average deviation' is an index that shows stability of heart function and is shown low in angry. worried, scared state. 'Pulse average deviation' is shown higher as color temperature increases and fury, worry, horror are determined to be lower when color temperature gets higher (5600 K > 3800 K > 2000 K).

In 'sympathetic activation', 'sympathetic activation', 'pulse average deviation', there was meaningful correlation between illuminance and color temperature and different difference shown according to the combination of illuminance and color temperature. Sympathetic activation win 2000 K and 3800 K was shown the lowest in 300 lx among illuminance level but in case of 5600 K it was the highest in 300 lx showing relatively no difference between illuminance level. 2000 K and 3800 K 'Parasympathetic activation' showed low activation in 300 lx but 5000 K showed higher activation as illuminance gets higher. 'Pulse average deviation' as well showed same trend with sympathetic and parasympathetic activation when 2000 K and 3800 K and activation was shown to increase as illuminance gets higher in 5600 K. Ratio of sympathetic and parasympathetic and pulse average deviation has no statistically meaningful difference and 2000 K and 3800 K sympathetic activation, parasympathetic activation, pulse average deviation showed the trend that activation decreases as illuminance increases but in the opposite, 5600 K shows high activation as illuminance increases so 2000 K and 3800 K lowered nervousness, excitement while increasing fury, worry, horror and 5600K increased nervousness, excitement while lowering fury, worry and horror.

Table 7. Two-way ANOVA analysis result

assessment	DV	source	p<0.05	η
HRV	LF	Illuminance	.017	.026
		CT	.216	.010
		Illuminance * CT	.013	.039
	HF	Illuminance	.176	.011
		CT	.051	.019
		Illuminance * CT	.015	.038
	LF/HF	Illuminance	.224	.009
		CT	.990	.000
		Illuminance * CT	.422	.012
	SDNN	Illuminance	.126	.013
		CT	.073	.016
		Illuminance * CT	.204	.019
	RMSSD	Illuminance	.103	.014
		CT	.011	.028
		Illuminance * CT	.003	.049

6. Conclusion

Comfort perception was shown positively more in normal lighting (3800 K) than warm lighting (2000 K) showing comfort in 150 lx positively unlike results of other prior researches. In low color temperature like warm lighting (2000 K), people perceived warmness more than normal lighting (3800 K) but it was shown that they perceive visual comfort such as naturalness, softness, shine less positively. Thus, it is judged that visual comfort like naturalness, softness rather than warmness or cold of lighting tends to affect comfort perception and that correlation of illuminance and color temperature affects the perception of illuminance quality.

As a result of evaluating occupants mood by lighting environment, negative emotions such as 'nervousness', 'depression', 'fury', 'fatigue', 'confusion' get lowered especially as illuminance gets higher showing positive change psychologically in bright lighting environment rather than in dark lighting environment. As a result of statistical analysis, on changes in automatic nervous system, sympathetic activation was shown to have meaningful difference by illuminance. Since sympathetic activation is shown low as illuminance is higher and high in nervous, excited state, we can say that higher illuminance(300 lx > 150 lx > 50 lx) lowers nervous, excited state. Since higher color temperature creates higher pulse average deviation, it was shown that higher color temperature (5600 K > 3800 K > 2000 K) lowers fury, worry, horror. Since cool lighting like the research result of Jung, Woo-Suk and 3 others (2007) was shown to lower fury, worry and horror, color temperature was judged to have more influence on fury, worry and horror while nervousness, excitement get lowered with higher illuminance thus it is considered that they are hugely affected by illuminance.

Perception on illuminance intensity, pleasantness perception, occupants mood. sympathetic activation of automatic nervous system were shown positively as illuminance is higher (300 lx > 150 lx > 50 lx) and comfort was shown positive in 150 lx. Comfort was shown in 3800 K color temperature and perception on lighting

intensity, pleasantness, worry, fury, horror were shown the most positive in 5600 K.

Resting work is the work that aims for physiological and psychological stabilization thus space considering physiological and psychological health is needed. Dark lighting condition like 50 lx and warm lighting of 2000 K increase visual unpleasantness and psychological anxiety together with nervousness, excitement, fury, worry, horror physiologically thus it is considered that color temperature higher than 3800 K and illuminance level higher than 150 lx would be needed upon designing indoor lighting condition for physiological and psychological health of occupants.

This research is limited because there is a possibility that vision of when research participation is being done and physical status of subjects affect HRV although noise and temperature-humidity conditions are all set same then preceded to every subject as much as possible. Maximum illuminance range was not presented because more illuminant condition than 50 lx, 150 lx, 300 lx에서 300 lx that are illuminance conditions could not be evaluated. Since this research evaluated only one resting work targeting only 20s subject, it is considered that evaluation regarding physiological and psychological changes of occupants in various actions and research targeting subjects at various range of age are considered to be done additionally in future research work.

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References

[1] IESNA, The Lighting Handbook, 10th Edition, 2011
[2] 주은철, IT 융합과 LED 산업동향, BIR RESEARCH GROUP, pp.95-105, 2011 // (Ju eun-cheol, IT yunghapgwa LED saneopdonghyang, BIR RESEARCH GROUP, pp.95-105, 2011)
[3] 산업통상자원부(2011.8.11.), LED가 녹색패러다임 변화를 주도한다. http://www.mke.go.kr, 2014.09.22.확인 // (Ministry of Trade, Industry and Energy(2011.8.11.), LEDga noksaek paereodaim byeonhwareul judohanda .http://www.mke.go.kr, 2014.09.22.checked.)
[4] 박현수, 인간적이고 스마트한 LED 감성조명, 대한전기학회 전기의 세계 제60권 제6호, pp.19-24, 2011 // (Park Hyeon-su, ingan chinhwajeokleego smart han LED gamseong jomyeong, The Korean Institute of Electrial Engineers, jeongiui segye, 60(6), pp.19-24, 2011)
[5] 이종춘, 조명핸드북, 성안당, pp.161-163, 2010 // (Lee Jong-chun, jomyeng handbook, seong an dang, pp.161-163, 2010)
[6] 윤규현, "주거공간의 재실자 행위별 조명환경 요소의 시각적 성능 평가", 경희대학교 석사학위논문. 2014 // (Yoon, Gyu Hyon, Visual Performance of Physical Luminous Elements on Occupants' Behavior, Kyunghee Univ, master's degree thesis, 2014)
[7] 김수연, 주거공간에서의 행동유형에 따른 조명환경 평가에 관한 연구, 충남대학교 박사학위논문, 2013 // (Kim, So-Yeon, A Study on the assessment of the illumination environment by behavior pattern in residential spaces, ChungNam Univ, doctor degree thesis, 2013)
[8] 박현수, 정연홍, 유세준, 장우진, 조도와 색온도에 기초한 조명의 질적 특성에 관한 주관 평가, 한국조명전기설비학회 2012 춘계학술대회 논문집, pp168-169,2012 // (Hyensou Pak, Yeon-Hong Jeong, Se-Jun Yu, Woojin Jang, Subjective Evaluation of Lighting Quality Based on Illuminance and Color Temperature, The Korean Institute of Illuminating and Electrical Installation Engineers, 2012 spring conference, pp.168-169, 2012)
[9] 노정림, "조도 변화에 따른 단위공간에서의 감성 연구", 호서대학교 석사학위논문. 2012 // (Jeong-Lim Roh, A Study on the Emotion in the Unit Space through Illuminance Variation, Hoseo University, master's degree thesis, 2012)
[10] 지순덕, 최경재, 김호건, 이상혁, "LED 기반 백색 조명의 색온도 및 연색지수에 따른 감성 평가", 감성과학 v.9 n.4. 2006 // (Soon Duk Jee, Kyoung Jae Choi, Ho Kun Kim, Sang Hyuk Lee, Sensibility Evaluation of Color Temperature and Rendering Index to the LED-Based White Illumination. 2006)
[11] 정우석, 유미, 권대규, 김남균, "색채 조명 자극이 인지기능에 미치는 영향에 관한 연구", 한국정밀공학회지 제 24권 제10호. 2007 // (Woo Suk Chong, Mi Yu, Tae Kyu Kwon, Nam Gyun Kim, Study on the Effect of Cognitive Function by color Light Stimulation, Journal of the Korean Society for Precision Engineering, v.24 n.10. 2007)
[12] T.Y.Hwang, D.G.Lee, J.T.Kim, Optimal Illuminance of Seven Major Lighting Colours in LED: Focus on Occupant Comfort and Communication in an Indoor Environment, Indoor and Built Environment, 21(1), 122-128, 2011
[13] 지식경제부 기술표준원, "KS A 3011 조도 기준" 2014.06 개정 // (The Ministry of Knowledge Economy Korean Agency for Technology and Standards, "KS A 3011 Illuminance Standard" 2014.06 revision)
[14] JIS Z 9110, General rules of recommended lighting levels, 2010
[15] Küller, R., & Wetterberg, L Melatonin, cortisol, EEG, ECG and subjective comfort in healthy humans: Impact of two fluorescent lamp types at two light intensities. Lighting Research & Technology, 25(2), 71-81. 1993
[16] Küller, R., & Wetterberg, L. The subterranean work environment: Impact on well-being and health. Environmental International, 22(1), 33-52. 1996
[17] M. Johansson, E. Pedersen, P.Maleetipawan-Mattsson, L. Kuhn, T. Laike .Perceived outdoor lighting quality (POLQ): A lighting assessment tool, Journal of Environmental Psychology, 39, pp.14-21. 2014
[18] McNair DM, Lorr M, Droppleman LF. Profile of Mood States Manual. San Diego: Educational & Industrial Testing Service; 1992

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