The effect of insufficient artificial lighting on workers’ moods and physiology: preliminary research

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Abstract. In line with the sustainability issue, the current research related to lighting has been focused on maintaining the health and well-being of the workers, not only for energy saving considerations. This preliminary research observed the effect of artificial light below the recommended illuminance levels for the workplace on the workers’ moods and their physiological condition. The researchers employed a quasi-experimental approach by observing the participants’ sleepiness state, mood, and physiological condition related to their cortisol levels in the first two and last two hours of their work shift. The research subjects were five male printing workers who worked in the basement of an office building in Sleman Regency, Special Region of Yogyakarta, Indonesia. As the room was below the ground floor, to accommodate their work activities, the employees relied on artificial lighting, complemented by a small amount of natural lighting entering the basement. The lighting was measured on the illuminance level of 250s lx and the CCT of 5000s K. The research revealed that there is no complaint or problem regarding the illuminance level, no effect on the individuals’ state of sleepiness, or on their moods. However, the cortisol level tended to decrease faster than the normal circadian curve. Therefore, it is reasonable to conclude that even though ‘insufficient’ lighting levels can accommodate activities, the physiological condition of the subjects shows different results which indicate a negative increment.

Keywords: CCT, cortisol, illuminance level, sleepiness, working place

1. Introduction

Along with rapidly developing lighting technology, energy saving which is the philosophy of sustainable development, is no longer a dominant issue in lighting-related research, as that research is now orienting towards human-centered studies [1]. The direction of research development that considers humans is still in line with the sustainable environment when considering the fundamental formulation for ‘sustainable habitat’ offered by Kawase (2005) [2]. The formulation or stated as ‘throughput formula’ [3] proposes that \( T = W - D \). The formula states that throughput (T) is welfare (W) where the latter consists of: (i) safety, (ii) relief, (iii) health, and (iv) comfort minus environmental damage (D) [2]. Human-centered research is a part of improving health and welfare that must be maximized.

Visual-related lighting criteria include: (1) brightness levels, (2) visual clarity, (3) color, and (4) ambiance preferences [4]. Therefore, to save energy and cost the user can lower the level of lighting [5] as long as it does not reduce visual comfort for those individuals within that environment [6]. Lighting levels that are lower than the standard can still accommodate work activities [7]. The strength of light
received by the human eye’s pupil is lower than that emitted by a light source, and in one study there were no complaints about it [8]. Another study showed that the illuminance level does not affect an individual’s level of alertness [9] or work performance [10]. On the contrary, some studies found that lighting levels that are lower than the standard can cause eyes fatigue [11] and lead to ‘sick building syndrome’ [12].

However, some researchers have stated that lighting has an impact not only in the form of image formation in the retina but also on non-image-forming factors related to circadian cycles and/or rhythms [13], including the setting of the human biological clock [14]. This non-image-forming issue shows the role of lighting relating to the regulation of a person’s levels of arousal and mood [15]. Following this conclusion, another study by [16] suggested that lighting with a low correlated color temperature (CCT) and illuminance levels can create a better mood in recipients. Lighting with high CCT is preferred if it is at a high illuminance level. To: (a) reduce drowsiness, (b) improve focus, (c) improve concentration, and (d) enhance well-being, high illuminance levels are needed (1700-2500 lux) [17]. Another article concludes that exposure to high illuminance levels is beneficial for performance and reduces the prevalence and levels of negative moods [18]. This current article aims to explain the results of preliminary research into the effect of artificial lighting below the recommended standards on the moods and physiological condition of indoor workers.

2. Literature review

2.1. Recommended lighting standards for the workplace

Office brightness recommendations often differ depending on the type of work taking place in that lighting. In general, the guidance of lighting for offices in Indonesia is in terms of illuminance level, CCT, and the ‘color rendering index’ (CRI) [5]. The choice of CCT depends on the illuminance level needed to obtain comfortable lighting. The recommended CCT ranges from 4000 K-6500 K, which generally creates a comfortable lighting environment for the user. However, if a high level of illumination is not needed, the recommended CCT is in the range of 2300-3500 K.

An illuminance level of 300 lx is the recommended standard for reception rooms, meeting rooms, and active archive rooms. The recommended requirement for ‘director’ rooms, workrooms, and computer rooms is 350 lx. While the illuminance level of 750 lx is required for spaces in which accurate technical drawing and other similar activities are taking place. The illuminance level of 150 lx is the standard for archive warehouses and emergency stairs. Reception rooms and meeting rooms can apply CCT warm (< 3300 K) and warm white (3300 K - 5300 K). The ‘director’ rooms, workrooms, computer rooms, drawing rooms, archive warehouses, and active archive rooms apply warm white (3300 K - 5300 K) and cool daylight (> 5300 K). The recommended CRI for all rooms except meeting rooms in the workplace is CRI group 1 (Ra index of 81% ~ 100%) and CRI group 2 (Ra index of 61% ~ 80%).

Other workplace standards, such as those applicable to general industrial buildings, recommend CCT in the warm white of 3300K-5300K and cool daylight of >5300K ranges. For menial jobs, the recommended illuminance level is 200 lx, while CRI is at group 2 or 3 (Ra index of 40% ~ 60%). The recommended illuminance level of 500 lx and CRI at group 1 and 2 are for intermediate work. The recommendation of illuminance level for fine work, pure fine work, and color checking is 1000 lx, 2000 lx, and 750 lx, respectively, and at CRI level 1. For incidental rough work the standard required is 100 lx; 200 lx for continuous rough work; 300 lx for routine work, 500 lx for moderate fine work, and 1000 lx for fine work. 1500 lx is recommended for pure fine work and 3000 lx for detailed work that needs to avoid shadow [19].

2.2. The non-image forming effects of lighting in the workplace

Due to its non-image forming function, artificial lighting has been shown to significantly influence the moods of office workers [20] as well as a person’s levels of brain activity [21]. In mood conditioning via the medium of light, the cortisol hormone functions as a stress hormone and melatonin hormone functions as a sleep hormone. Cortisol plays a significant role in regulating the alertness and quality of sleep; its levels increase in the morning and prepare the body for activity. The normal range of cortisol
level is 50 – 230 ng/ml at 8.00 – 10.00 and 30 – 150 ng/ml at 16.00 [22]. If cortisol levels are too high for a long time, that condition will result in the person experiencing fatigue, caused by excess of the hormone. The cortisol levels then gradually decrease. However, the level is likely to remain sufficient to provide blood sugar and energy throughout the day. The cortisol hormone then reaches its lowest level at about midnight [14]. Melatonin is known as a sleep hormone, as it has been shown to regulate sleepiness [23].

![Figure 1. Typical daily rhythms of cortisol for a natural 24-hour light/dark cycle [14]](image)

Lighting is proven to have an impact on humans’ cognitive, affective, and motivational processes that have consequences, amongst other things, for work productivity levels [24]. Lighting settings at daytime have the potential to optimize the individual’s subjective responses and performance [18]. Exposure to artificial morning sunlight improves cognitive performance. The illuminance levels of artificial morning sunlight are 0-250 lx for 30 minutes before waking up, and 250 lx for 20 minutes after waking up increase cognitive performance [25]. Exposure to short-wavelength light in the afternoon can immediately increase a person’s alertness [26]. Lighting can also affect mood conditioning by creating various impressions via a range of lighting arrangements and illuminance levels [27]. Therefore, to increase positive moods such as enthusiasm and temporary satisfaction levels, general lighting is used. To reduce negative moods like anxiety, stress, and fatigue, indirect or ambient lighting is employed [28]. Response speeds on spatial measurement tests and verbal memory can measure lighting’s effects upon a person’s psychological and cognitive performance levels [29].

Subjective alertness is related to the level of lighting [30]. The lighting level affects the level of a person’s alertness and the incidence of work errors. Lower levels of lighting can cause fatigue, thereby reducing work speed [31]. Bright lighting is useful for improving the alertness and mood of workers during working hours [32] compared to lamps providing light of a lower intensity [26]. The higher the lighting level and the colour temperature of the lamps, the more suitable the illumination is for people in areas which require their functionality whereas the relaxation area can apply a low light temperature colour [33]. A person’s: (a) perception, (b) memory function, and (c) learning also improve with high and identical illuminance levels and medium and high CCT. Low and identical illuminance levels and moderate CCT are suitable for increasing performance levels of thinking and decision-making [34].

Increased CCT or illuminance levels during the day can control the secretion of melatonin [35]. Increasing CCT and illuminance levels in the morning effectively restrained the melatonin secretion of the study’s subjects [35]. The lighting dimensions of CCT 2877-3856 K have the potential to affect psycho-biological parameters related to workers’ wellbeing, with the illuminance levels in the horizontal plane of 450 - 800 lx [36].

However, high illumination also brings about a slow response time, where backlighting that is too bright can cause a distraction of a respondent’s attention during performance testing [37]. The illuminance level of 165 lx, 600 lx, 1700 lx in the morning, and afternoon affects physiological and performance conditions, although there appears to be no fixed pattern to this sequence [9]. In another
study, the observed illuminance level did not show a significant effect on mood over time [38]. Also, it has been suggested that the use of bright light cannot reduce sleepiness and improve performance [23].

3. Research method
This research is part of a dissertation research that was approved for its ethical clearance by the ethical committee of the Universitas Gadjah Mada in April 2020. Included in the quasi-experiment, the study observed the consequences of situations arising from natural events involving independent variables that are not directly controlled by researchers [39]. The research used a survey technique to evaluate the existing conditions.

The researchers conducted observations of print workers located in the basement of an office on Jalan Jembatan Baru UGM (69PF + R9 Sinduadi, Sleman Regency, Yogyakarta Special Region). The lack of natural sunlight makes the basement dependent upon the artificial light which may, in turn, lead to greater risk on health problem [40]. It is widely known that light has positive and/or negative effects on mood, therefore underground workplace should carefully choose the lighting type being provided [41]. The observations were conducted in a real workplace without any special treatment or facilities related to, or designed to facilitate, research. The room observed has a neutral character with white walls and ceiling, as is often noted in similar research [42,43] and off-white colouring of floor materials. Other research [44] has used ‘real’ rooms for data gathering related to the effect of lighting on mood. However, such ‘real-life’ research environments make it difficult to control the incoming lighting, which can be seen as a weakness of such real-life studies [45].

The research subjects were five male printing employees (average 25.8 yo) who did not receive any special treatment or preparation prior to the research. The five employees selected were male in order to avoid the need to take into account the effects of the menstrual cycle on a worker’s mood [46]. The research was conducted on May 18, 2020. During the observation, the subjects did Ramadhan fasting and worked as usual. Researchers observed the conditions in the first two hours and the last two hours of working time: (a) in the morning session from 08.00-10.00 and (b) in the afternoon session from 14.00-16.00. Data were collected after 20 minutes of exposure to light. In each of the two sessions (morning and afternoon), data collection was carried out four times every half hour.

The data collected was subjective, reinforced by samples of the research subjects’ physiological indicators. The subjective data related to: (1) drowsiness levels using the Karolinska Sleepiness Scale (KSS) on a scale of 1-9 and (2) mood with the Visual Analogue Scale (VAS) on a scale of 0-100. The KSS method is considered sensitive, reliable, and valid for measuring drowsiness, where the objective method is impossible to apply, as in this example of work related activities [47]. On the KSS scale, one represents very alert, while nine means very sleepy. VAS has proven its reliability and validity in detecting changes in mood [48]. For VAS, a scale of 0 represents a very bad mood while a scale of 100 represents a very good mood. Physiological observation data was collected in the form of salivary cortisol. The cortisol hormone as a marker of stress [49] is a potential indicator related to mood [50]. This data collection method combines subjective data (KSS and VAS) and physiological observations; an approach which has succeeded in proving that the effect of certain types and levels of artificial lighting is able to counter, or even overcome, morning sleepiness [51].

Data from KSS and VAS are calculated based on the average of the observations made in order to identify the existence of a trend. Cortisol analysis uses ELISA, a biochemical test that involving antibodies and enzyme-mediated colour changes to detect the presence of antigens or antibodies in samples [52]. The results of the ELISA analysis are then compared with the normal daily curve, especially the cortisol trend, to see its suitability. If the sampled data fails to match the anticipated trend, it is possible be that one causal factor for this anomaly could be linked to the artificial lighting.

4. Findings and discussion
The observed effect of artificial lighting on the mood and physiological conditions of the five male workers is down-light-direct-lighting with an illuminance level of 250s lx and CCT of 5300s K. The observed basement also received limited levels of natural lighting. However, this source did not have a
significant effect when seen in the lighting conditions shown in Figure 1. The lighting quantity in the basement was deemed not sufficient to meet the recommended standard of 750 lx to accommodate the printing activities involving white paper and color checking [5] and choosing [19] such as book and cover editing, printing and finishing.

![Figure 1. Basement lighting conditions](image)

**Figure 2.** Basement lighting conditions on (1) 8.30; (2) 8.50; (3) 9.20; (4) 9.50; (5) 14.20; (6) 14.50; (7) 15.20; and (8) 15.50.

4.1. **Subjective assessment**

Figure 3 presents the result of measuring the levels of sleepiness based on the KSS questionnaire. The questionnaire results’ graph did not show a significant difference either in the morning or afternoon. If level one represented very alert, then the subjective average drowsiness was entirely stable on a scale level of 2.425 indicating that the sleepiness felt by the subjects was quite low. The same steadiness was shown by the VAS results of subjective mood in Figure 4 that were almost stable both in the morning and afternoon. If a score of 100 represents a very good mood, then the average mood level was relatively steady on a scale of 82.75; indicating the level of mood felt by the subjects was quite good throughout their working day.

![Figure 3. KSS result on sleepiness scale](image) ![Figure 4. VAS result on mood scale](image)

This good result might be influenced by the Hawthorn effect, since the subjects were workers from one printing office, so there might be concerns that the supervisors will see the bad results (if any). Therefore, subjects tended to provide positive results in sleepiness and mood related variables. The
subjects reported a lack of sleep that might be because the research itself was carried out during the fasting month hence the subjects had to get up before the dawn to do *sahur*.

4.2. **Physiological observation**

Figure 4 shows salivary cortisol concentration in morning and afternoon observations.

![Figure 4. Salivary cortisol concentration in morning and afternoon observations.](image)

**Figure 4.** Salivary cortisol concentration in morning and afternoon observations.

Figure 5 shows the ELISA result on salivary cortisol concentration level.

![Figure 5. ELISA result on salivary cortisol concentration level.](image)

**Figure 5.** ELISA result on salivary cortisol concentration level

When compared with the typical daily rhythms curve of cortisol in Figure 1, the measurement at 08.00-10.00 showed a 65.56% decrease from average of 12.69 to 4.37 ng/ml cortisol level. That decrease is in line with the declined line at 15.00 – 17.00 level of typical daily rhythms of cortisol. Meanwhile, the measurement results at 14.00-16.00 showed a 45.63% decreasing of cortisol level from average 4.06 to 2.21 ng/ml that corresponded to a flat line at the 21.00 – 23.00 level of typical daily rhythms of cortisol. The observed cortisol trend curve did not show the expected level of hormone at the time of observation. What it did show was that the physiological conditions of the subjects, under exposure to artificial lighting below the recommended standard, did not have the levels of stress hormone concentration that were expected to support the work performance.

Fasting may have influenced the results of studies on hormone concentrations. Research on the effect of fasting on physiological responses, situational awareness, and driving performance in the morning concludes that fasting has been shown to significantly reduce heart rate [53]. Heart rate itself has been used to confirm research related to the effect of lighting on mood in the elderly [54]. However, the change of cortisol level is still expected to show the same shape with the typical daily rhythms curve of
cortisol, even though it exists under 50 – 130 ng/ml as normal conditions, rather than a significant decrease.

![Figure 6. Comparation of research result and typical daily rhythms curve of cortisol [14]](image)

5. Conclusion
The insufficient lighting does not have a subjective evaluation effect related to sleepiness and mood. However, it does affect the physiological condition of the subject by decreasing cortisol levels trend drastically. If considering the typical daily rhythm, a low cortisol concentration can be interpreted as an increase in the hormone melatonin that leads to a decrease in alertness. It can be concluded that insufficient lighting in workplace may not be suitable for maintaining worker’s mood based on physiological data.

There are several limitations that might need to be improved in the next research. The number of research subjects might be too small hence cannot provide strong evidence for the conclusion. Fasting conditions were never considered in previous similar studies, as most such research was conducted in contexts where fasting was rare rather than an accepted socio-cultural norm. Thus, this issue will be considered in the next research. This study did not include a performance test, which would have yielded a greater quantity of valid data. The study also limited the observations to the initial 2 hours and the last 2 hours of working time, so that the cortisol trend curve was broken and did not show complete results. Therefore, observing the effect of lighting exposure on mood should be carried out continuously during working hours to obtain a complete unbroken condition curve.

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References
[1] Jarboe C, Snyder J and Figueiro M G 2020 The effectiveness of light-emitting diode lighting for providing circadian stimulus in office spaces while minimizing energy use Light. Res. Technol. 52 167–88
[2] Kusumawanto A and Astuti Z B 2018 Arsitektur Hijau dalam Inovasi Kota (Yogyakarta: Gadjah Mada University Press)
[3] Hayashi T, Matsufuji Y, Takasu K, Nomura K and Hosokawa T 2005 Assessment Concept of Architecture of Habitat System for Sustainable Development The 2005 World Sustainable Building Conference (Tokyo) pp 1920–5

[4] Khanh T Q, Bodrogi P, Guo X and Anh P Q 2019 Towards a user preference model for interior lighting. Part 2: Experimental results and modelling Light. Res. Technol. 51 1030–43

[5] Badan Standardisasi Nasional 2011 SNI 6197: 2011 Konservasi Energi pada Sistem Pencahayaan (Jakarta)

[6] Tsushima S, Tanabe S and Utsumi K 2015 Workers’ awareness and indoor environmental quality in electricity-saving offices Build. Environ. 88 10–9

[7] Kuraseng H and Jamala N 2016 Analisis Standar Iluminasi pada Ruang Kerja Kantor Temu Ilmiah IPLBI pp 25–30

[8] Vieira Dias M, Motamed A, Sergio Scarazzato P and Scartezzini J L 2017 Toward proper evaluation of light dose in indoor office environment by frontal lux meter Energy Procedia 122 835–40

[9] Huijberts L M, Smolders K C H J and de Kort Y A W 2016 Non-image forming effects of illuminance level: Exploring parallel effects on physiological arousal and task performance Physiol. Behav. 164 129–39

[10] Huijberts L M, Smolders K C H J and de Kort Y A W 2015 Shining light on memory: Effects of bright light on working memory performance Behav. Brain Res. 294 234–45

[11] Ramadhani A F 2012 Analisis Tingkat Pencahayaan dan Keluhan Mata pada Pekerja di Area Produksi Pelumas Jakarta PT Pertamina (Persero) Tahun 2012 (Universitas Indonesia)

[12] Ratodi M, Zubaidah T and Marlinae L 2017 Predicting the Sick Building Syndrome (SBS) occurrence among Pharmacist assistant in Banjarmasin South Kalimantan Heal. Sci. J. Indones. 8 118–23

[13] Benarroch E E 2011 The melanopsin system: Phototransduction, projections, functions, and clinical implications Neurology 76 1422–7

[14] van Bommel W J M 2006 Non-visual biological effect of lighting and the practical meaning for lighting for work Appl. Ergon. 37 461–6

[15] Bowrey H E, James M H and Aston-Jones G 2017 New directions for the treatment of depression: Targeting the photic regulation of arousal and mood (PRAM) pathway Depress. Anxiety 34 588–95

[16] Lee J-H, Moon J and Kim S 2014 Analysis of Occupants’ Visual Perception to Refine Indoor Lighting Environment for Office Tasks Energies 7 4116–39

[17] Aries M B C 2005 Human Lighting Demands: healthy lighting in an office environment (Eindhoven University Press)

[18] Ru T, de Kort Y A W, Smolders K C H J, Chen Q and Zhou G 2019 Non-image forming effects of illuminance and correlated color temperature of office light on alertness, mood, and performance across cognitive domains Build. Environ. 149 253–63

[19] Anon 2002 Keputusan Menteri Kesehatan Republik Indonesia Nomor 1405/MENKES/SK/XI/2002 tentang Persyaratan Kesehatan Lingkungan Kerja Perkantoran dan Industri (Republic of Indonesia)

[20] Fleischer S, Krueger H and Schierz C 2001 Effect of brightness distribution and light colours on office staff: Results of the “Lighting Harmony” project 9th Eur. Light. 76–80

[21] Park J Y, Min B K, Jung Y C, Pak H, Jeong Y H and Kim E 2013 Illumination influences working memory: An EEG study Neuroscience 247 386–94

[22] CBI Cortisol Saliva ELISA (The Calbiotech Inc.)

[23] Lok R, van Koningsveld M J, Gordijn M C M, Beersma D G M and Hut R A 2019 Daytime melatonin and light independently affect human alertness and body temperature J. Pineal Res. 67 1–10

[24] Kombeiz O 2016 Turning the spotlight on the role of light and colors in offices: How are performance, social interactions, and social perception affected? (University of Hohenheim)
[25] Gabel V, Maire M, Reichert C F, Chellappa S L, Schmidt C, Hommes V, Cajochen C and Viola A U 2015 Dawn simulation light impacts on different cognitive domains under sleep restriction Behav. Brain Res. 281 258–66
[26] Lin J, Westland S and Cheung V 2020 Effect of intensity of short-wavelength light on electroencephalogram and subjective alertness Light. Res. Technol. 52 413–22
[27] Durak A, Camgöz Olguntürk N, Yener C, Güvenç D and Gürçinar Y 2007 Impact of lighting arrangements and illuminances on different impressions of a room Build. Environ. 42 3476–82
[28] Hsieh M 2015 Effects of Illuminance Distribution, Color Temperature and Illuminance Level on Positive and Negative Moods J. Asian Archit. Build. Eng. 14 709–16
[29] Hawes B K, Brunyé T T, Mahoney C R, Sullivan J M and Aall C D 2012 Effects of four workplace lighting technologies on perception, cognition and affective state Int. J. Ind. Ergon. 42 122–8
[30] van Duijnhoven J, Aarts M P J, Rosemann A L P and Kort H S M 2018 Ambiguities regarding the relationship between office lighting and subjective alertness: An exploratory field study in a Dutch office landscape Build. Environ. 142 130–8
[31] Boyce P R 1970 The influence of illumination level on prolonged work performance Light. Res. Technol. 2 74–94
[32] Zhu Y, Yang M, Yao Y, Xiong X, Li X, Zhou G and Ma N 2019 Effects of Illuminance and Correlated Color Temperature on Daytime Cognitive Performance, Subjective Mood, and Alertness in Healthy Adults Environ. Behav. 51 199–230
[33] Van Erp T a. M 2008 The effects of lighting characteristics on atmosphere perception (Eindhoven University of Technology)
[34] Sun C, Lian Z and Lan L 2019 Work performance in relation to lighting environment in office buildings Indoor Built Environ. 28 1064–82
[35] Yang C, Yang P, Liang S and Wang T 2019 The effects of illumination and correlated colour temperature on daytime melatonin levels in undergraduates with sub-syndromal SAD Light. Res. Technol. 1–14
[36] Tonello G, Hernández de Borsetti N, Borsetti H, Tereschuk L and López Zigarán S 2019 Perceived well-being and light-reactive hormones: An exploratory study Light. Res. Technol. 51 184–205
[37] Min B K, Jung Y C, Kim E and Park J Y 2013 Bright illumination reduces parietal EEG alpha activity during a sustained attention task Brain Res. 1538 83–92
[38] Küller R, Ballal S, Laike T, Mikellides B and Tonello G 2006 The impact of light and colour on psychological mood: A cross-cultural study of indoor work environments Ergonomics 49 1496–507
[39] Groat L and Wang D 2013 Architectural Research Methods (New Jersey: John Wiley & Sons. Inc)
[40] Nang E E K, Abuduxike G, Posadzki P, Divakar U, Visvalingam N, Nazeha N, Dunleavy G, Christopoulos G I, Soh C K, Jarbrink K, Soljak M and Car J 2019 Review of the potential health effects of light and environmental exposures in underground workplaces Tunn. Undergr. Sp. Technol. 84 201–9
[41] Soh C K, Christopoulos G, Roberts A and Lee E H 2016 Human-centered Development of Underground work Spaces Procedia Eng. 165 242–50
[42] Kocaoglu R 2015 The Effect of Correlated Color Temperature in Sustained Attention and Mood of University Students in Learning Environments (Ihnan Dogramaci Bilkent University)
[43] Smolders K C H J and de Kort Y A W 2017 Investigating daytime effects of correlated colour temperature on experiences, performance, and arousal J. Environ. Psychol. 50 80–93
[44] Figueiro M G, Steverson B, Heerwagen J, Kampschroer K, Hunter C M, Gonzales K, Plitnick B and Rea M S 2017 The impact of daytime light exposures on sleep and mood in office workers Sleep Heal. 3 204–15
[45] Leichtfried V, Mair-Raggautz M, Schaeffer V, Hamrer-Lercher A, Mair G, Bartenbach C, Canazei M and Schobersberger W 2015 Intense illumination in the morning hours improved mood and alertness but not mental performance Appl. Ergon. 46 54–9
[46] Wijayanto T, Tochihara Y, Wijaya A R and Hermawati S 2009 Combined factors effect of
menstrual cycle and background noise on visual inspection task performance: A simulation-based task. J. Physiol. Anthropol. 28 253–9

[47] Åkerstedt T, Anund A, Axelsson J and Kecklund G 2014 Subjective sleepiness is a sensitive indicator of insufficient sleep and impaired waking function J. Sleep Res. 23 240–52

[48] Monk T H, Buysse D J, Reynolds C F, Berga S L, Jarrett D B, Begley A E and Kupfer D J 1997 Circadian rhythms in human performance and mood under constant conditions J. Sleep Res. 6 9–18

[49] Sperlich B, Achtzehn S, Buhr M, Zinner C, Zelle S and Holmberg H C 2012 Salivary cortisol, heart rate, and blood lactate responses during elite downhill mountain bike racing Int. J. Sports Physiol. Perform. 7 47–52

[50] Bluyssen P M, Janssen S, van den Brink L H and de Kluizenaar Y 2011 Assessment of wellbeing in an indoor office environment Build. Environ. 46 2632–40

[51] Choi K, Shin C, Kim T, Chung H J and Suk H J 2019 Awakening effects of blue-enriched morning light exposure on university students’ physiological and subjective responses Sci. Rep. 9 1–8

[52] Gan S D and Patel K R 2013 Enzyme immunoassay and enzyme-linked immunosorbent assay J. Invest. Dermatol. 133 1–3

[53] Fitriansyah H 2016 Analisis Pengaruh Kondisi Berpuasa terhadap Respon Fisiologis, Situation Awareness dan Performansi Mengemudi di Pagi Hari (Universitas Gadjah Mada)

[54] Kuijsters A, Redi J, De Ruyter B and Heynderickx I 2015 Lighting to make you feel better: Improving the mood of elderly people with affective ambiences PLoS One 10 1–22