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Impact of dynamic lighting control on light exposure, visual comfort and alertness in office users

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Abstract. The lighting environment at indoor workplaces is important not only to provide vision and visual comfort, but also for light's direct influence on human physiology, cognitive performance and mood. The purpose of this ongoing study is to investigate the impact of a dynamic control of combined daylight and artificial lighting on office users' visual comfort as well as on alertness and cognitive performance. We are going to evaluate the impact of two different office lighting conditions in a quasi-real setting on subjective alertness ratings in healthy young participants over several days. We will compare an office with optimized daylighting and artificial lighting, operated by a new control system with a standard office room, where the lighting/shading can be changed manually. The aim of this balanced crossover within study design is to show that exposure to optimized dynamic lighting control over several days is superior on subjective alertness and glare indexes, when compared to a conventional lighting control. Here, we present some preliminary results from the first six participants on the comparison of subjective evaluations of alertness and the objective monitored (day-) light exposures and glare index Daylight Glare Probability (DGP) in the two different conditions over one week (five days) each.

1. Introduction

In the last two decades many studies have shown that light has a fundamental impact on human physiology and health, and can directly boost alertness, cognitive performance, as well as improve our mood [1], [2]. Most people in industrialized societies spend 90% of their time in buildings, where a poor and inappropriate exposure to daylight can lead to circadian misalignment and thereby increasing the risk for sleep disorders, fatigue, performance problems, hormone and metabolic disorders. The Non-Image-Forming (NIF) effects of light are currently not sufficiently considered for lighting of indoor working environments such as in offices. However, taking these effects into account is important to improve well-being and productivity of users. In the framework of this study, which is carried out in the Solar Energy and Building Physics Laboratory (LESO-PB) in EPFL, we are going to evaluate the impact of two different lighting conditions in offices on well-being and subjective alertness in healthy young participants over several days. The aim is to show that an optimal dynamic lighting control, integrating both natural and artificial light, has beneficial effects on the aforementioned aspects if compared to a manual lighting control. This ongoing study has started in September 2018. In this conference proceedings we present preliminary results of subjective alertness and DGP ratings for six study volunteers, as well as lighting parameters such as vertical illuminance, glare index and melanopic irradiance (measured at the corneal level). Previous studies with similar objectives and innovative methodologies performed at EPFL indicated the need for integration of visual comfort, nonvisual light effects and thermal comfort in office spaces [3]–[6].

2. Methods

2.1. Experimental set-up

The study is currently carried out in two identical office rooms in the LESO solar experimental building on the EPFL campus (Switzerland). Both rooms are south-oriented and occupied by a single user. An advanced controller for venetian blinds and electric lighting is designed to dynamically and continuously provide predefined (optimized) lighting quality and quantity in the first office (= test room). Specifically, the position and slat angle of the blinds as well as the dimming level of the electric lighting are adjusted based on the current indoor lighting conditions. In the second office (= reference room), there is no automated system in place, and no optimized daylighting system, the occupant is free to adjust electric lighting and blinds according to their preference. The top window in the reference room (anidolic daylighting system [7]) is covered, in order to cut out part of the daylight influx and make the room more similar to a standard office lighting condition (Figure 1).

The assessment of lighting parameters inside the office is performed by High Dynamic Range (HDR) vision sensors [8] and a spectrometer placed at the eye level next to the workstation. For this long-term study we will include thirty-four participants between 19 and 30 years old. Each participant will spend one week in the test room and one week in the reference room, in a cross-over-within-participant design. During the time spent in the offices at usual office hours, i.e. 8 hours per day between approximately 8:00 and 18:00 (based on their habitual wake times – see below) - participants carry out their usual visual task (e.g. studying, reading, etc.) and regularly perform some cognitive performance tests at the computer. They also complete surveys throughout the day to evaluate their physical, physiological and psychological well-being, alertness, mood and visual comfort. Furthermore, wearable photometric sensors fixed on a glasses frame are used to monitor light exposure at the eyes.

The study was initiated in September 2018 and is currently ongoing.

a)

b)

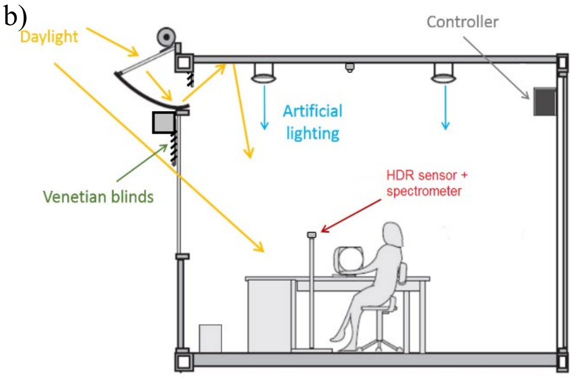

Figure 1. (a) View of the two office rooms. On the left side: test room, with ADS and automated control of venetian blinds and electric lighting; on the right side: reference room, with ADS closed and manual control of blind and lighting. (b) Cross-section scheme of an office room.

2.2. Subjective alertness ratings
On a typical study day in the laboratory, participants answer an online survey eight times at regular time intervals. One of the questions included in the latter is: "Indicate on the scale how do you feel in this moment". To answer, the participant indicates on a Visual Analogue Scale (VAS) his/her alertness level, from 0 (extremely alert) to 100 (extremely sleepy). This results in eight subjective alertness ratings per day. In this conference proceedings we present preliminary results from six participants.

2.3. Illuminance and glare at the corneal level
HDR vision sensors (developed in collaboration with the *Centre Suisse d'Electronique et de Microtechnique* - CSEM, Switzerland) are placed at the approximate eye level of the user who is sitting at the desk. These sensors continuously capture luminance maps with a monitoring interval of about 2 minutes: an embedded software extracts the vertical illuminance E_v (expressed in lux) as well as the glare index Daylight Glare Probability (DGP) [9] from the luminance distribution [8]. This glare index is based on the contrast of luminance within the field of view and on the average vertical illuminance; it represents the probability of experiencing discomfort glare and is expressed by a relative fraction (%).

2.4. Melanopic irradiance
A spectrometer (Specbos by JETI Technische Instrumente GmbH, Jena, Germany) placed next to the aforementioned vision sensors monitors the electromagnetic spectrum in the visible range between 400 and 780 nm with a monitoring interval of 5 minutes. At the end of the day, the spectra were collapsed into 30 min time bins, starting from each participants' arrival time in the office for the entire day. According to the CIE[10], the melanopic irradiance $E_{e,mel}$ [W m^{-2}] was calculated as the light spectrum weighted with the melanopic action spectrum $s_{mel}(\lambda)$, according to equation (1):

$$E_{e,mel} = \int E_{e,\lambda}(\lambda)\, s_{mel}(\lambda)\, d\lambda \tag{1}$$

3. Preliminary results and discussion
Here we report some preliminary results averaged across five days per condition for six study volunteers. Since the exact time schedule for each participant was based on their habitual sleep-wake time, there is not a unique starting and finishing time in the laboratory for all participants. Extreme chronotypes (i.e. morning and evening types) are not included, and the starting time of the protocol for the first six participants was between 8:45 and 9:15. For the sake of consistency, data were aligned according to the elapsed time in the office (from 0 to 9 hours, including one-hour lunch break). The data presented here were collected between September 2018 and April 2019.

3.1. Light and glare at the corneal level
Figure 2 and Figure 3 show the time course of the illuminance E_v and glare index DGP acquired by the HDR sensors placed at the eye level in each of the two conditions averaged across 5 days in half-hourly intervals. We can qualitatively observe that a generally higher E_v was recorded in the test room until 6 hours after the start time (i.e. around 15:00), which decreased and was kept slightly lower than in the reference condition for the remainder the day. This trend of E_v in the test room reflects the aim of the controller for blinds and electric lighting, to provide a dynamic lighting to the user with a natural time course in terms of vertical illuminance. In the reference room, E_v increases in the afternoon due to the orientation of the participants' desk and the sensors. Indeed, the user is facing West, which is where the sun is in the afternoon at this time of the year. The graphs show that more direct sunlight results in an increase in recorded illuminance (and DGP).

The DGP is a proxy for perceived discomfort glare, the threshold for perceptible glare sensation as defined by the standard EN 17037:2018 (recommendation for intensive protection against glare) [11] being equal to 35% and is reported in Figure 3. The average DGP was maintained below this threshold in both office lighting conditions. These results visually confirm the proportionality between DGP and E_v: the DGP is slightly higher in the test room, although it is always within the acceptable range for visual comfort.

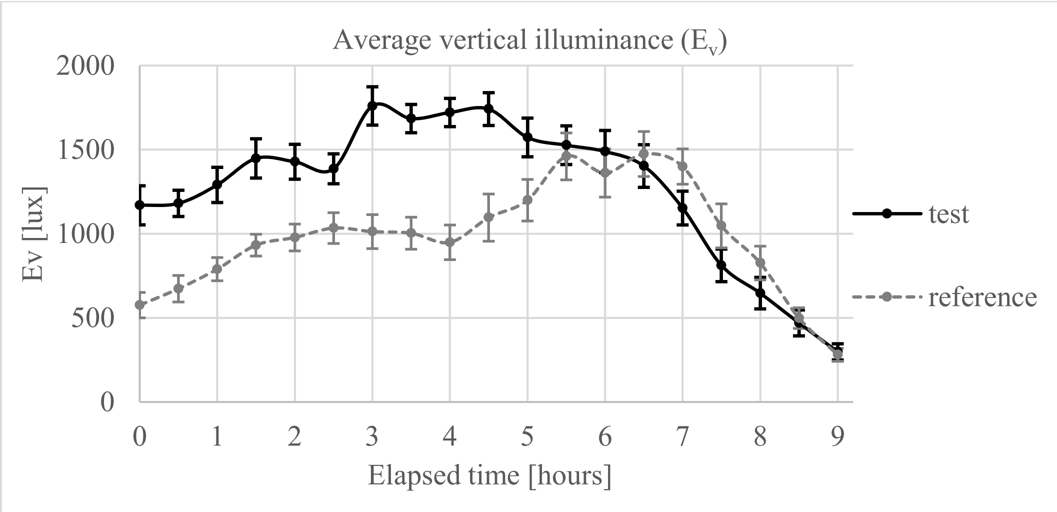

Figure 2. Average vertical illuminance at the eye level assessed by HDR vision sensors in the two conditions. Means across 6 participants (±SEM) and 5 days per condition.

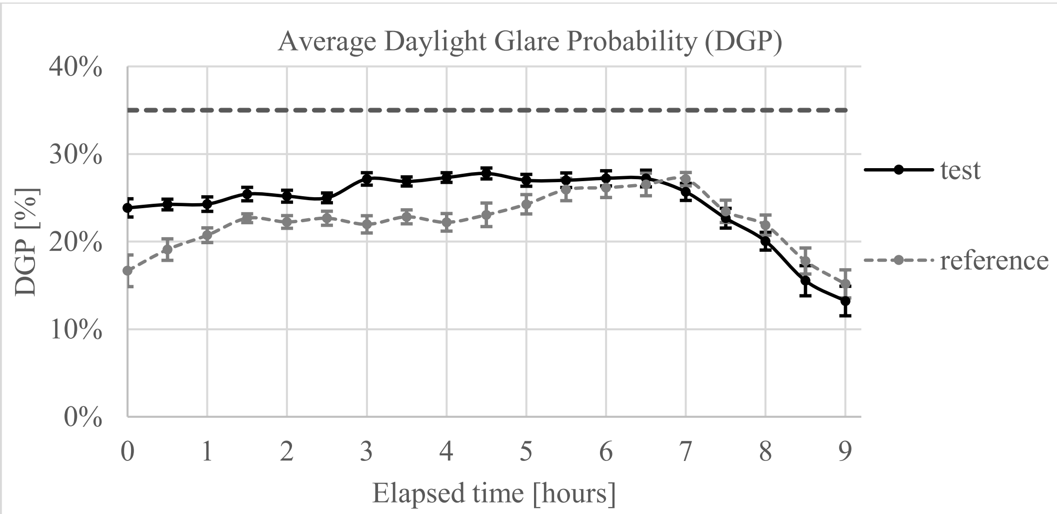

Figure 3. Average Daylight Glare Probability (DGP) assessed by HDR vision sensors in the two conditions. The thick dashed line indicates the threshold for perceptible glare sensation (lower is better). Means across 6 participants (±SEM) and 5 days per condition.

3.2. Melanopic irradiance

Figure 4 shows the melanopic irradiance $E_{e,mel}$ averaged for six participants in the two different office lighting conditions. Again, higher averaged values were recorded in the test than the reference room (similar to E_v) with higher values in the first part of the day and lower after mid-afternoon. On the other hand, it seems that after 7 elapsed hours, melanopic irradiance was slightly larger in the reference room.

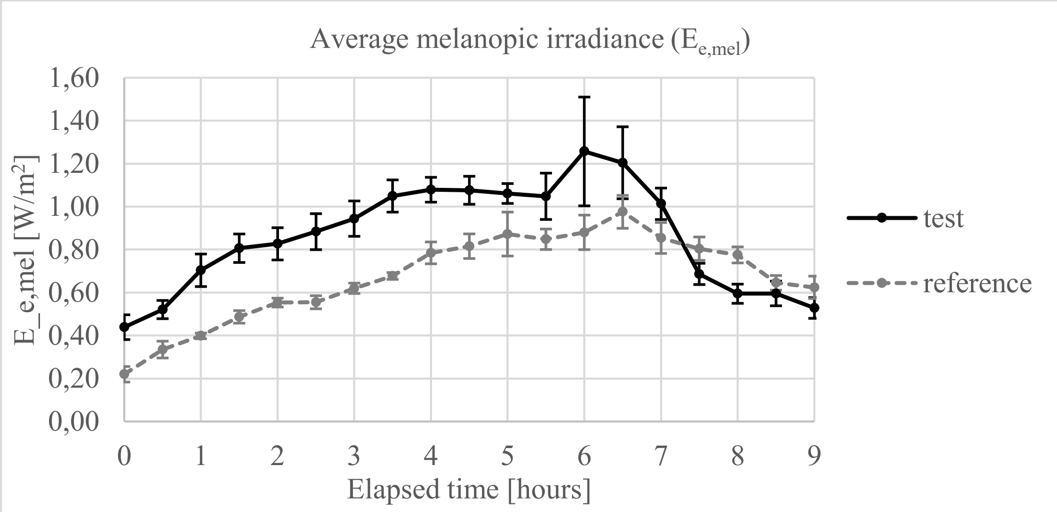

Figure 4. Average melanopic irradiance in the two conditions. Means across 6 participants (±SEM) and 5 days per condition

3.3. Subjective alertness

The average time course of subjective alertness ratings are illustrated in Figure 5. The y-axis scale ranges from 0 (extremely alert) to 100 (extremely sleepy). In both office lighting conditions, subjective alertness does not vary throughout the day, it seems to stay at a consolidated alert level.

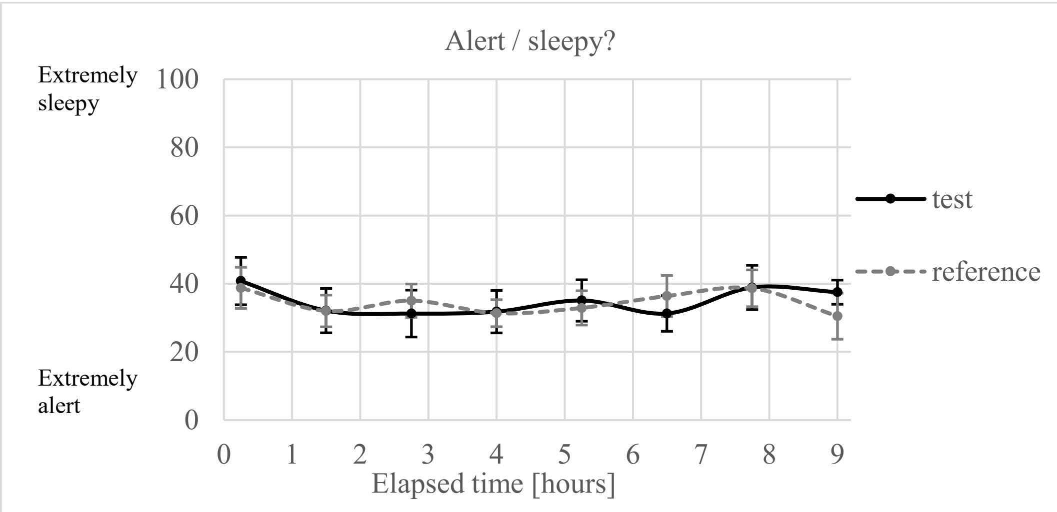

Figure 5. Average subjective alertness rating in the two conditions. Means across 6 participants (±SEM) and 5 days per condition

4. Conclusion

We presented the first preliminary results of this ongoing long-term study, which is aimed at investigating the impact of different office lighting conditions on several aspects of human physiology and well-being. We qualitatively presented some preliminary results from six participants: recorded vertical eye illuminance, glare index, melanopic irradiance and subjective alertness ratings. These first results are promising and we can observe higher illuminance and melanopic irradiance in the test room in the first part of the day without induced glare. These first results suggest and confirm the expected performance of the automated controller for blinds and electric lighting in providing the desired indoor lighting quality and quantity. Regarding subjective alertness, no visually significant differences were found between the two lighting conditions. Data from all participants will be needed in order to statistically analyse them with sufficient power and to conclusively interpret the results. We have been also monitoring many other aspects not reported here, which we are going to analyse and present in more details, such as cognitive performance, hormonal profiles -melatonin and cortisol, sleep quality and mood for instance.

5. Acknowledgements

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