BIODYNAMIC LIGHTING IN PRACTICE: PILOT STUDY IN A GOVERNMENT OFFICE

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Abstract

Biodynamic lighting was installed as a pilot on one floor of an existing government office. Occupant satisfaction, work performance effects and energy effects on this floor were systematically evaluated against the default situation on other floors. Apart from these themes, some unexpected lessons were learned about the implementation of biodynamic lighting in practice. Most noticeable, expectation management to the occupants and - for better acceptance - the importance of gradually increasing the control dynamics rather than starting with an extreme algorithm and slowly decreasing it. Considering that the whole aim of biodynamic lighting is to increase occupant wellbeing, these unexpected lessons will be valuable for further implementations of biodynamic lighting in practice.

Keywords: *biodynamic lighting, circadian lighting, occupant satisfaction, productivity*

1 Introduction

A pilot study with biodynamic lighting was conducted in a government office in use. The aim of the study was to investigate the pros and cons of biodynamic lighting in terms of energy use, occupant wellbeing and practical issues, and assess its potential for rollout over the full Dutch governmental building stock. The pilot was one part of a program that assessed several innovative technologies in a comparable manner. One other test floor in this office was equipped with phase change materials for passive temperature control, yet another floor had workplaces with optimised individual controls for desktop heating, cooling, personal ventilation and desktop lighting.

In the context of this study, biodynamic lighting is defined as ambient workplace lighting that can be varied in intensity and colour temperature during daytime, intending to mimic the diurnal cycle of natural daylight and thus improve the occupants' sleep/wake cycle. The hypothesis was that biodynamic lighting can stimulate employees' alertness at work and improve sleep quality and recuperation after hours. This should result in increased levels of wellbeing and productivity at no significant energy increase.

2 Methods

2.1 Overall setup of the experiment

Tuneable white LED lighting with a DALI-controlled clock program was installed on the 6th floor of a typical office building. A questionnaire was used to assess the occupant perception of the 6th floor lighting system in a steady output setting before and after the transition to LED lighting. Participants were employees of a governmental organisation located in the building and performed their usual work activities, mainly working on a computer and having meetings.

Then, an experiment including two dynamic lighting scenarios was run on the 6th floor, both interventions running for five weeks with a baseline of two weeks in between. The baseline conditions were 350 lux and 4000K, comparable to the light conditions on the other floors of the building. After the 2-weeks baseline period with steady state lighting, the first intervention (SCENARIO 1) took place in which the light intensity was varied over the office hours. It started at 350 horizontal lux in the morning, peaking at 1200 lux at noon and gradually dimming back to 350 lux over the afternoon. After complaints, the peaks were ultimately reduced to 800 lux.

After another steady state baseline period, the second intervention (SCENARIO 2) followed a similar dimming cycle and in addition changed in colour temperature from 3300K in the morning to 5000K at noon and back to 2800K in the late afternoon. The interventions were symmetrically planned around the solstice (21st December) to obtain a comparable bias by daylight hours. The experiments took place from November 2019 until February 2020 (Figure 1).

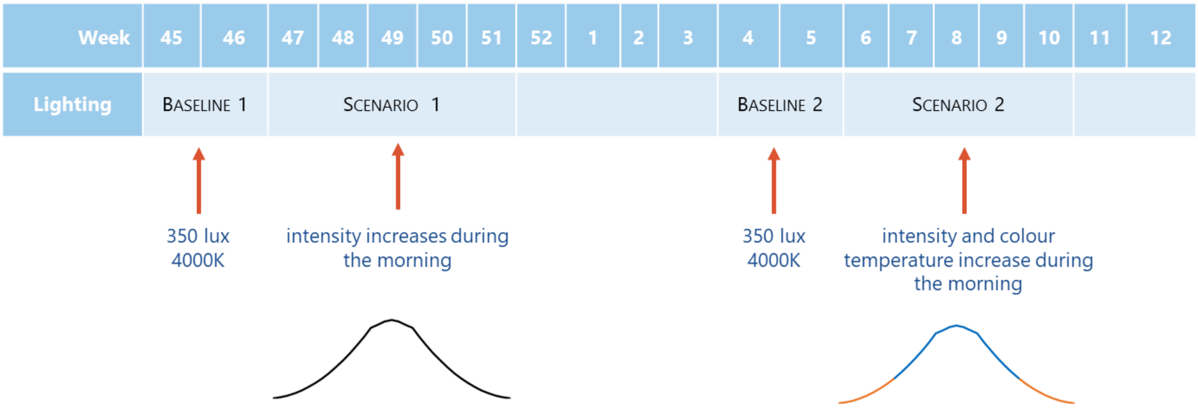

Figure 1 – Phasing of the experiment.

Before, during and after the interventions, the occupants' response was assessed using two types of evaluations:

1. A questionnaire at the end of each intervention, to evaluate the overall experiences.
2. A test block consisting of a different questionnaire, combined with performance tests, to gauge the momentaneous situation during Default 1 and at the start and end of SCENARIO 1.

2.2 Evaluating questionnaire

In the evaluating questionnaire over the past month, several typical symptoms of indoor environmental discomfort were assessed on a 7-point scale: 1 for strongly dissatisfied, 4 for neutral and 7 for strongly satisfied. Both the degree of dissatisfaction and the percentage of dissatisfied respondents (=scores 1 to 3) were evaluated. The symptoms covered various themes in the categories *Temperature*, *Light*, *Sound*, *Air quality*, *Perceived control* and *Self-estimated productivity effects*. The questionnaires also included open questions to allow for open feedback.

The self-assessed productivity and alertness as a result of the indoor environment at the workplace was also evaluated on a 7-point scale, running from -30% to +30% productivity. Respondents were also asked to estimate the influence of the indoor environment on their work performance and alertness on a 7-point scale.

Health and wellbeing-effects over the past month were assessed using a series of yes/no-questions on several typical workplace related health symptoms.

2.3 Momentaneous questionnaire

The acute effect of the current indoor environment on subjective alertness was assessed using the 9-point Karolinska Sleepiness Scale (Akerstedt, 1990), combined with the assessment of temperature and light conditions on a 7-point scale. Respondents were asked to rate their experience (e.g. *cold* to *warm*) as well as their verdict: *comfortable* or not.

2.4 Performance tests

Before, during and after the interventions, the occupants' performance was assessed using three validated productivity tests from the Cambridge Brain Sciences cognitive test battery: *Double Trouble*, *Rotations* and *Spatial Planning Task* (Sahakian, 1988).

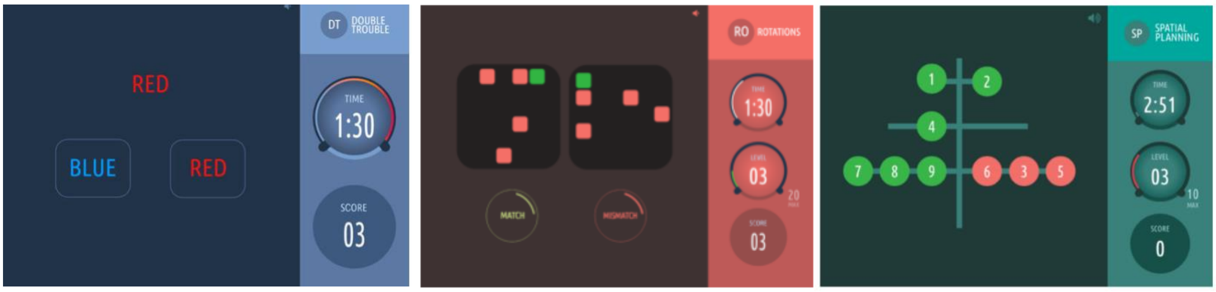

Figure 2 – screenshots from *Double Trouble*, *Rotations* and *Spatial Planning Task*

2.5 Energy monitoring

Before, during and after the experiment, energy consumption was monitored for each floor in the building by a third party.

3 Results

3.1 User satisfaction dynamic lighting scenarios

The SCENARIO 1 questionnaire had 25 respondents and SCENARIO 2 had 16 respondents. The evaluation of the steady state lighting (BASELINE) compared to the dynamic lighting scenarios showed lower occupant satisfaction during the dynamic conditions (Figure 3). Moreover, during SCENARIO 2, 18% of the respondents indicated to be very dissatisfied (score 1), while none of the respondents indicated to be (very) satisfied (score 6 or 7). Remarkably, the percentage of people satisfied was higher during Default 2 (68% and 92% respectively) although light exposure was te same.

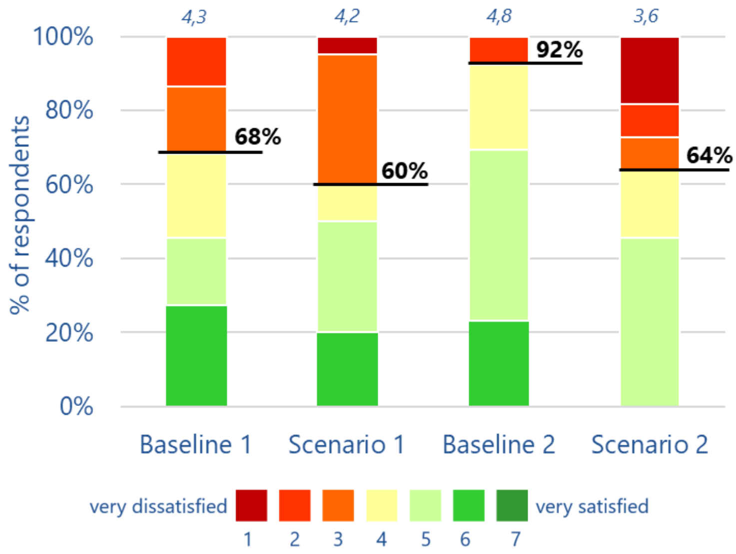

Figure 3 – Percentage of people satisfaction for the different lighting conditions.

Respondents indicated why there were not satisfied with the lighting conditions (Table 1): "Too much artificial light" was mentioned by about half of the respondents during both dynamic lighting scenarios. During SCENARIO 2, 45% of the respondents also mentioned that light had a "Undesirable colour". Finally, it is notable that in general, respondents were not satisfied with the view outside. From the oral evaluation it was reported that especially the noticeable transitions in colour temperature and intensity, the perceived brightness of the lighting scene, discomfort due to glare and lack of personal control were reported to cause visual discomfort.

Table 1 - Complaints about the lighting conditions during the different scenarios.

	BASELINE 1	SCENARIO 1	BASELINE 2	SCENARIO 2
Too bright	9%	25%	8%	27%
Too dark	9%	10%	0%	0%
Not enough daylight	26%	35%	38%	18%
Too much daylight	4%	0%	8%	9%
Not enough artificial light	4%	0%	8%	9%
Too much artificial light	22%	45%	23%	55%
Lighting flickers	0%	0%	15%	0%
Glare	9%	5%	0%	18%
Reflections in the screen	9%	10%	23%	0%
Shadows on desk	0%	0%	0%	0%
Undesirable color of lighting	9%	0%	15%	45%
Limited view to the outside	43%	40%	62%	27%
Uninteresting/ unpleasant view	17%	15%	54%	27%

Finally, the respondents also indicated how they perceived the lighting condition at the beginning and at the end of the light scenario. The majority of the respondents experienced the baseline condition between "neutral" and "bright", while SCENARIO 1 was perceived as "very bright" during the first week of exposure. After four weeks (in the meantime the maximum light intensity was decreased from 1200 lux to 800 lux), respondents perceived the lighting intensity comparable to the baseline condition. In line with these results, light intensity was perceived uncomfortable during the first week of SCENARIO 1 and slightly comfortable to comfortable at the end of SCENARIO 1 and during BASELINE 1.

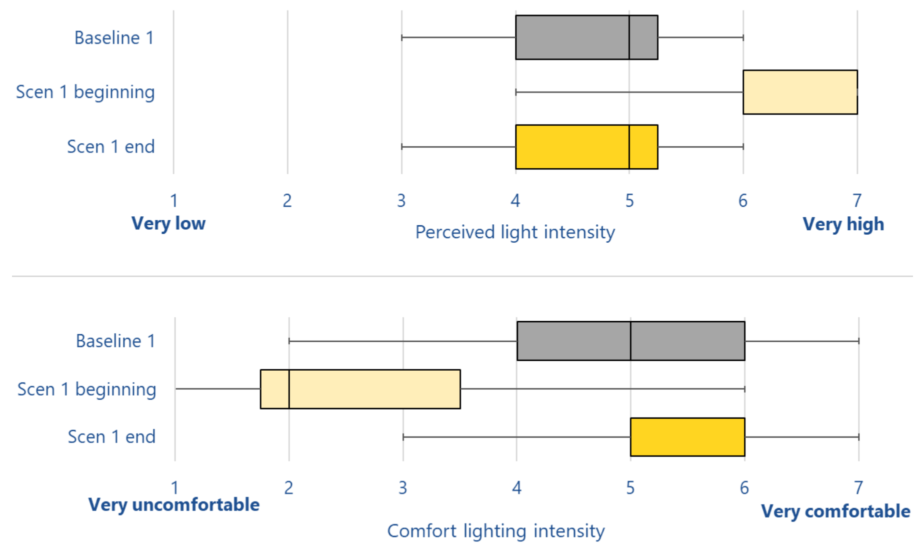

Figure 4 – Perceived light intensity and comfort during BASELINE 1 and SCENARIO 1 (after 1 week and during the final week)

3.2 Experienced control

Perceived control over lighting was generally very low during the study; both during the baseline as the dynamic lighting scenarios (Figure 4). In the first basic condition, just over 60% of the respondents still experience some degree of control. During the other scenarios, this has decreased and three-quarters of the respondents experienced no control over the lighting at all. This while the control opportunities were the same during all scenarios.

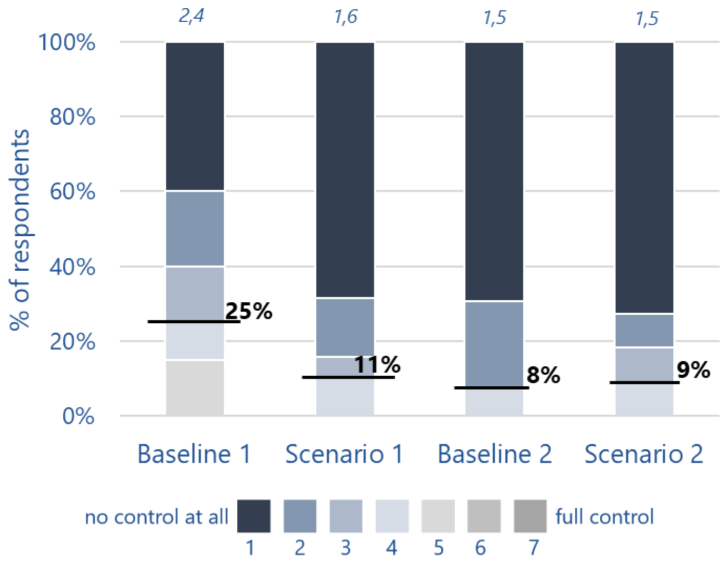

Figure 5 – Perceived control over light conditions

3.3 Productivity

3.3.1 Self-assessed productivity & alertness

During BASELINE 1, respondents indicated that they expect the indoor environment to negatively affect (on average -6%) their productivity and alertness (Figure 6). During the other scenarios the respondents, on average, expected the indoor environment not to affect (SCENARIO 1 and 2) or positively affect their productivity (BASELINE 2). Only during BASELINE 1, respondents indicated that the indoor environment negatively influenced their alertness. However, it should be noted that individual responses are scattered.

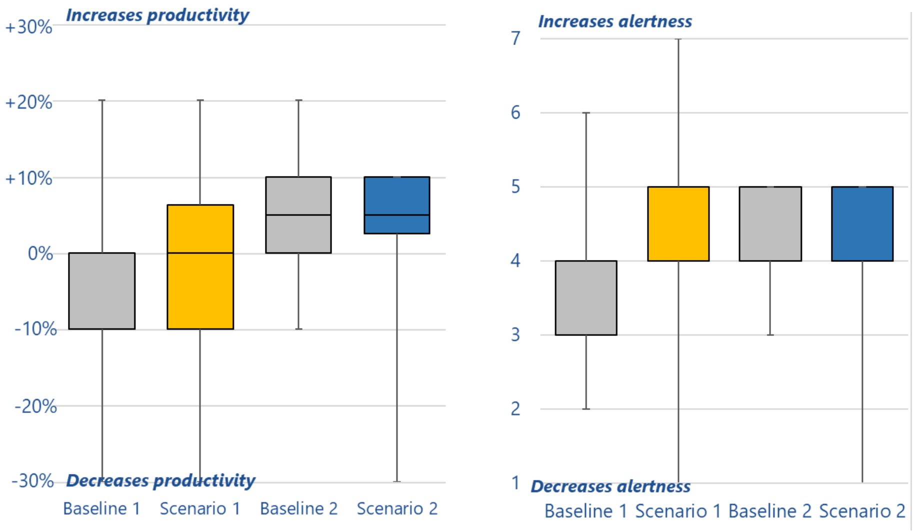

Figure 6 - Self-assessed productivity (left) and alertness (right) during the baseline and both dynamic lighting scenarios.

Alertness during BASELINE and SCENARIO 1 was evaluated using the Karolinska Sleepiness Scale (KSS). On average respondents indicated to be reasonably alert (score 3,9). During the first week of SCENARIO 1 the outcome was comparable, while during the final week the alertness was increased and 50% of the respondents indicated to feel “alert” or “very alert” (Figure 7).

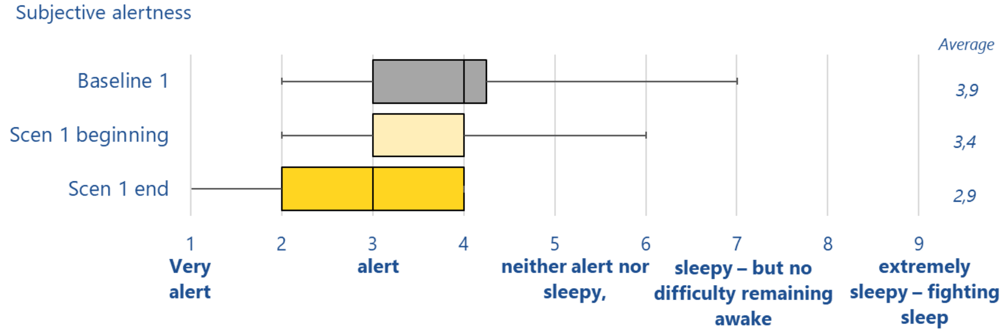

Figure 7. Self-assessed alertness during BASELINE 1 and SCENARIO 1 (after 1 week and during the final week)

3.3.2 Productivity tasks

During baseline conditions and during the first week of SCENARIO 1, participants performed productivity tasks (Figure 8). On average the scores (based on time, correct and false answers) are comparable between the light conditions but individual differences are large. In comparing the results during the morning and the afternoon: during the morning the scores are higher during SCENARIO 1 while during the afternoon the score was higher during BASELINE 1. The differences are not significant, since difference between participants were large and within subject comparison was not possible.

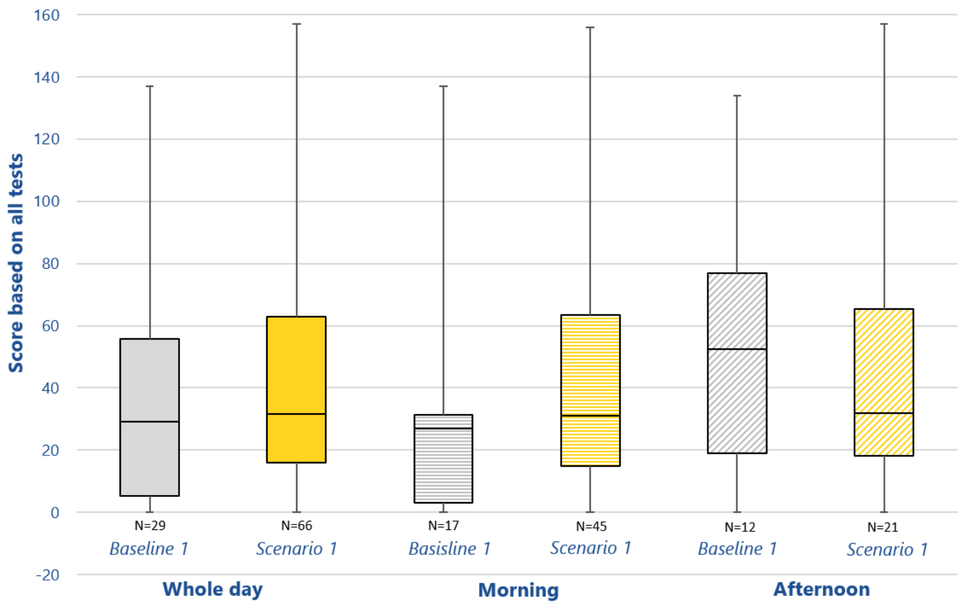

Figure 8. Scores of the productivity task during BASELINE 1 and SCENARIO 1 for the whole day and split of the results during the morning and afternoon.

3.4 Energy consumption

The interventions had a significant effect on the energy consumption and increased along with an increasing light intensity. Compared to the baseline scenario of 350 lux, daily energy use increased with about 40% when increasing light intensity to 800 lux. For the scenario with a maximum light intensity of 1200 lux, daily energy use for lighting doubled.

4 Discussion

The pilot with individually controlled desktop lighting elsewhere in the building received mixed appreciation. The chosen fixtures with a rather narrow beam, combined with a strongly reduced background level, resulted in dark/light spots that were found uncomfortable. However, the possibility of individual control was clearly appreciated.

Likewise, lack of personal control was an important complaint by the respondents of this study, especially during the interventions. It seems likely that lack of control would be regarded as much less of an issue if the lighting situation was in better connection with the occupant's comfort zone. This suggests that improved occupant control can increase their satisfaction with biodynamic lighting. In this study, occupants show considerable individual differences in appreciation of the same lighting scenarios. The overall appreciation may considerably increase if each occupant can create their personal favourite biodynamic lighting scenario, or at least adjust the standard scenario as programmed.

It was interesting to find differences in satisfaction between the two baseline light scenarios, as these were technically similar. These differences may be explained by previous lighting scenarios, influencing the appreciation by the respondents. E.g. if the baseline scenario was initially rated as 'neutral, it may seem 'good' after a bad experience with an uncomfortable intervention.

Differences in percentages complaints about view (lower during SCENARIO 2) may also be explained by the artificial lighting discomfort taking first stage, taking attention away from other forms of discomfort.

Self-reported productivity and wellbeing varied a little between scenarios, however differences were too small or inconclusive for attributing them to the specific interventions. Due to the expected effect size, the sample size and unexpected influencing factors, it can *not* be concluded whether or not the biodynamic protocols resulted in non-visual effects.

Self-assessed alertness increased slightly during SCENARIO 1. However, SCENARIO 2 did not show such an increase. Therefore, it cannot be concluded from these results whether this is solely an effect of biodynamic lighting.

Productivity tests performed in the morning scored a bit better in the SCENARIO 1 conditions than in default conditions. In the afternoon, it was the other way around. It should be noted that the box plots show considerable individual differences on this matter. In such a situation, inter-person responses to changes of scenario are more informative than average responses for the whole population, but this could not be done with this dataset. Therefore, the observed effects may seem smaller than the individual effects actually were.

5 Conclusions

Although with n=25 and n=16 the response on the scenario questionnaires was limited, and although the study is inconclusive about the non-visual effects of biodynamic lighting, some valuable lessons were learned for further pilot studies and, ultimately, successful implementation of biodynamic lighting. Especially non expected factors such as noticeable dimming steps, apparently lasting occupant aversion of the whole concept after a rather high-stimulus experiment start, and fading participants interest should be considered in further studies and application.

It was also concluded that in a field experiment, many factors outside working hours influence the outcome measures on productivity and wellbeing thereby requiring a large sample size to detect possible effects of the dynamic light scenarios.

Anyhow, it can be concluded that providing lighting conditions in an office that both connect to the occupants' non-visual needs as well as their visual needs is still a challenge. As individuals have different preferences for lighting intensity and colour temperature at different hours of the day, a biodynamic lighting installation designed according to common guidelines may receive better acceptance if implemented with a certain degree of personal control.

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