The effects of dynamic lighting on office workers : first-year results of a longitudinal field study

Proceedings

EXPERIENCING LIGHT 2009

International Conference on the Effects of Light on Wellbeing

Y. A. W. de Kort, W. A. IJsselsteijn, I. M. L. C. Vogels,
M. P. J. Aarts, A. D. Tenner, & K. C. H. J. Smolders (Eds.)

Keynotes and selected full papers
Eindhoven University of Technology,
Eindhoven, the Netherlands, 26-27 October 2009

Volume Editors

Yvonne de Kort, PhD
Wijnand IJsselsteijn, PhD
Karin Smolders, MSc
Eindhoven University of Technology
IE&IS, Human-Technology Interaction
PO Box 513, 5600 MB Eindhoven, The Netherlands
E-mail: {y.a.w.d.kort, w.a.ijsselsteijn, k.c.h.j.smolders}@tue.nl

Ingrid Vogels, PhD
Visual Experiences Group
Philips Research
High Tech Campus 34, WB 3.029
5656 AE Eindhoven, The Netherlands
E-mail: ingrid.m.vogels@philips.com

Mariëlle Aarts, MSc
Eindhoven University of Technology
Department of Architecture Building and Planning
PO Box 513, VRT 6.34
5600 MB Eindhoven, The Netherlands
E-mail: M.P.J.Aarts@tue.nl

Ariadne Tenner, PhD
Independent consultant
Veldhoven, The Netherlands
E-mail: ariadne.tenner@onsmail.nl

ISBN: 978-90-386-2053-4

Copyright:

Reference specification:
Name Author(s), “Title of the Article”, In: Proceedings of EXPERIENCING LIGHT 2009 International Conference on the Effects of Light on Wellbeing (Eds. Y.A.W. de Kort, W.A. IJsselsteijn, I.M.L.C. Vogels, M.P.J. Aarts, A.D. Tenner, and K.C.H.J. Smolders), 2009, pp. X (startpage) – Y (endpage).

Effects of Dynamic Lighting on Office Workers: First-year Results of a Longitudinal Field Study

Yvonne de Kort
Human-Technology Interaction
Eindhoven University of Technology
5600 MB Eindhoven, the Netherlands
+31 40 247 5754
y.a.w.d.kort@tue.nl

Karin Smolders
Human-Technology Interaction
Eindhoven University of Technology
5600 MB Eindhoven, the Netherlands
+31 40 247 3163
k.c.h.j.smolders@tue.nl

ABSTRACT

Dynamic lighting is designed to have positive effects on wellbeing and performance. In a field experiment we tested whether these effects are detectable and stable over time when employed in actual work settings. This 2-year study consists of two tranches, one following a monthly alternating experimental design, the other a yearly alternating one. This paper reports on the first tranche. In a fully counterbalanced design, office workers experienced dynamic or static lighting according to an a-b-a scheme over 3 consecutive periods (N=142, 90, and 83). Questionnaire data suggest no significant differences for need for recovery, vitality, alertness, headache and eyestrain, mental health, sleep quality, or subjective performance, although employees were more satisfied with dynamic lighting. Yet it is too early to discard the hypotheses and claims made about dynamic lighting altogether. Its effects may still emerge in environments with limited daylight, over a longer time period, or when more pronounced or differently shaped lighting patterns are applied.

Keywords

Dynamic Lighting, Wellbeing, Health, Performance

INTRODUCTION

Office work isn't all it's cracked up to be. Although not always physically challenging, having to deal with heaps of paperwork, incessantly incoming emails, and the constant buzz of phones, office humour, and printers rattling does take its toll on one's mental resources. On a more serious note, stress and attention fatigue are all too common in the office, so any environmental or ambient feature that holds the potential to revive office workers or help them recuperate from stress or fatigue throughout the day deserves our attention. In the current study we explore lighting as a potential environmental feature impacting office workers' wellbeing.

Artificial office lighting typically is constant in both intensity and colour temperature, whereas natural light varies throughout the day as a result of weather conditions and the position of the sun. Begemann, Van den Beld and Tenner [1] showed that peoples' preferences for artificial lighting vary with weather conditions and time of the day. Recent research has indicated that new lighting solutions may actually have an impact on biological and psychological processes.

Dynamic lighting is one of these innovative solutions, in which lighting characteristics such as colour temperature and intensity vary during the day according to a preset protocol. This should have a positive effect on users' wellbeing, health and performance. The rationale behind dynamic office lighting is that it supports the natural rhythm of employees' alertness [2]. An exemplary protocol – also applied in the present study – is presented in Figure 1. It is based on the idea that it stimulates workers during the (work) day by exposing them to a high lighting level and colour temperature in the morning and after lunchtime, and creating a relaxing environment with lower and warmer white light during the late morning and afternoon.

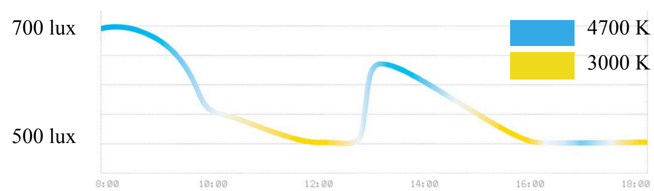

Figure 1. Protocol Philips dynamic lighting, source [2].

Light can influence the regulation of the biological clock, and the secretion of hormones such as melatonin and cortisol. During daytime the secretion of melatonin is low and therefore the influence of light on its suppression minimal [3]. Research has shown that the level of cortisol increases when exposed to high lighting levels in the morning, but not in the afternoon [3,4] or evening [5]. These biological effects are dependent on the colour temperature, lighting level, duration and timing of exposure, as well as on the size and position of the light source [2,6,7,8] and probably have an influence on individuals' wellbeing, health and performance [9].

Light also has a direct effect on people's alertness and sleepiness [2], apart from its indirect effect via the biological clock. Research into the psychological effects of lighting suggests that both a high intensity and a high colour temperature can have positive effects on people's wellbeing, health and performance. For instance Fleischer, Krueger and Schierz [10] showed that exposure to higher colour temperature lighting (5600K) is more stimulating than warm white lighting (3000K). Participants did indicate that they experienced the warm white lighting as more pleasant. Some smaller studies also showed an activating effect of a higher colour temperature (6500-7500K) compared to 3000 K lighting [11,12]. Other studies, however, failed to demonstrate comparable effects (see e.g. [13,14]), so overall the literature is still inconclusive. Employing more extreme lighting conditions, Viola and colleagues [15] found an effect of high colour temperature (17000K) on workers' ability to concentrate, level of fatigue, alertness, daytime sleepiness and subjective performance compared to a lower colour temperature (2900K). Lastly, Mills et al. [16] found comparable effects of colour temperature on wellbeing and performance of employees in a call centre. Yet the range of colour temperatures used in the current study is substantially lower.

Aries [17] reported an inverse correlation between lighting level and employees' level of fatigue and sleep quality. In an earlier experiment by Grünberger and colleagues [18], participants were exposed to either a high lighting level (2500 lux) or a lower lighting level (500 lux) for four hours between 9.00am and 5.00pm. The results showed that the higher lighting level had a positive effect on participants' alertness, their ability to concentrate, the number of errors they made on a performance test, and their mood compared to lower intensity lighting. Other studies also showed positive effects of a high lighting level on people's wellbeing and performance [e.g., 3, 19, 20]. It should be noted that in most of these studies the difference in lighting level between the high and low intensity lighting condition was large (>2000 lux).

Practically all of the rigorous scientific research into the biological and psychological effects of high intensity or high colour temperature office lighting was performed in laboratories, where participants are exposed to – sometimes extreme – lighting conditions for only short periods of time – typically several hours. Studies into the effects of dynamic lighting are scarce both in the field and in the lab and often involve only limited numbers of participants. User evaluation in realised projects shows anecdotal proof for increased wellbeing and performance amongst office employees (e.g., Interpolis and Trigion in the Netherlands, VUB bank in Slovakia). Whether these effects are detectable and whether they are stable over time when actually employed in the work setting has not been thoroughly investigated to date.

The present paper will report on intermediate results of the first large-scale field test into the effects of dynamic lighting for office workers. The longitudinal study follows an experimental design in two tranches, in which four groups of about 100 to 200 employees each are alternately exposed to dynamic and static lighting. In one tranche, which we are reporting on here, lighting conditions change on a monthly basis during winter months, counterbalanced over two groups. In the second tranche the lighting conditions remain stable during winter, dynamic for one group, static for the other. Then during summer both groups switch to the alternate condition. The advantage of this design is that we can both explore the relatively short and long-term effects of dynamic lighting compared to constant lighting. In addition, we can compare the two lighting conditions both between and within groups. In this paper, we describe the results of data gathered during the first winter for the two short-term groups (see Smolders & de Kort [21] for preliminary results of the second tranche).

METHOD

Design

The current study is a field experiment, with Lighting condition (dynamic vs. static) within, and Group (A vs. B) between groups, and three consecutive measurement periods (d-s-d and s-d-s scheme respectively, in January, February and March[1]). In other words, two groups of participants were exposed to dynamic or static lighting, alternating on a monthly basis and counterbalanced between groups. In the dynamic lighting condition, employees experienced a gradually changing lighting scenario with a higher lighting level (700 lux) and colour temperature (4700 K) in the morning and after lunchtime (see Fig1). The static condition had a 500 lux level of 3000K lighting.

The study was performed in a recently renovated high-rise office building, with a large daylight contribution (see Figure 2), in which a flex-working concept is applied. Daylight-dependent control was applied in both conditions. Investigation of the weather in first, second and third measurement period – weekdays of the two weeks before and one week during the survey – showed that during January there were more sun hours than in February and March (approximately 60, 35 and 40 respectively) [22].

Participants

In the first month of the field study, a questionnaire was distributed among 414 office employees from 7 departments, of which 147 were completed and returned (response rate: 35.5%). The data of five participants were removed because they indicated that they were only rarely at their workplace in the high-rise office building, that they were ill during the measurement period, or that they filled out the questionnaire at home. Of the remaining 142 participants (83 in the static and 59 in the dynamic condition), 111 were male and 31 female (mean age 45, SD = 10.23, range: 23 to 65).

[1] In the original design there were four measurement periods and the lighting condition would change three times. Due to technical problems, the study was delayed and it was not possible to have four measurement periods.

Figure 2. Picture of indoor environment

In the second measurement period, the questionnaire was again distributed and 96 employees (43 in the static and 47 in the dynamic condition) filled out the questionnaire completely (response rate: 23.2%). The data of six participants were removed because they indicated that they were only rarely at their workplace in the office or that they had filled out the questionnaire at home. Of the remaining 90 participants, 67 were male and 23 female with a mean age of 48 (SD = 9.73, range: 25 to 63).

In the third measurement period, 84 employees (42 in the static and 41 in the dynamic condition) completed the questionnaire (response rate: 20.3%). One participant filled out the questionnaire at home and his data was removed from the dataset. Of the remaining 83 participants, 68 were male and 15 female (mean age 48, SD = 9.45, range: 25 to 65).

Measures

The questionnaire consisted of measures for need for recovery (i.e., the need to recuperate from attention fatigue and stress), vitality, alertness, headache and eyestrain, mental health, sleep quality, and subjective performance. Subjective evaluations of lighting conditions were also assessed. In addition, attitudes towards the job and work environment and personal characteristics were included as control variables. Objective measures such as days of sick leave and coffee consumption were collected on department level to corroborate subjective findings.

Need for Recovery

Need for recovery was measured with a behaviour-based scale consisting of 34 items[2] describing behaviours at office employees' discretion to recover from mental strain, psychological distress, motivational deficits, and/or mental fatigue [23], combined with 11 evaluative statements by Van Veldhoven and Broersen [24]. Some items had 5-point response scales ranging from (1) 'never' to (5) 'very often' or from (1) 'never' to (5) 'at least once a day'. Other restorative activities had dichotomous response scales with either (1) 'It happens never or rarely' and (2) 'It happens sometimes or often' as response options, or with (1) 'yes' and (2) 'no' options. The evaluative statements are dichotomous items with (1) 'yes' and (2) 'no' as response options. Separation reliability of the scale was .83 in each consecutive month. The separation reliability matches with a classical definition of reliability; it represents the ratio between the true and estimated variance of people's recovery needs [25]. The reliability score of this scale thus indicates that scale's internal consistency is satisfactory.

Mental health and vitality

Mental health and vitality were assessed with two subscales from the Dutch version of the SF-36 Health Survey (RAND-36) [26]. The mental health subscale consists of 5 items, such as 'Have you been a very nervous person?' and had an internal consistency between $\alpha = .75$ and $\alpha = .81$. The vitality subscale consists of 4 items (e.g. 'Did you have a lot of energy?') with Cronbach's alpha between $\alpha = .76$ and $\alpha = .87$. The response options of both subscales ranged from (1) never to (5) very often.

Headache and Eyestrain

Headache and eyestrain were measured with 8 items adopted from Viola et al. [15], which describe symptoms, such as 'headache' and 'eye fatigue', with response options ranging from (1) 'absent' to (4) 'severe'. The scale had an internal reliability ranging from $\alpha = .84$ to $\alpha = .89$.

Alertness and sleep quality

Alertness was assessed with the Karolinska Sleepiness Scale [27] with 'today' instead of 'at this moment' as time frame. The response options ranged from (1) 'extremely alert' to (9) 'extremely sleepy - fighting sleep'. Sleep quality was measured with the Pittsburgh Sleep Quality Index [28] consisting of 18 items concerning subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, sleeping medication and daytime dysfunction. The scale has an internal consistency between $\alpha = .61$ and $\alpha = .70$.

Subjective performance

Subjective performance was measured with the question 'On a scale from 0 to 10, how would you rate your performance on the days you worked during the last 2 weeks?' derived from the World Health Organization Health and Work Performance Questionnaire (WHO-HPQ).

Subjective evaluations

Subjective evaluations of lighting conditions concern pleasantness of the lighting, experienced lighting level, experienced disturbances of the artificial lighting and of daylight, and satisfaction with the lighting. Pleasantness of the lighting was measured with two semantic differential adjective items (pleasant – unpleasant, comfortable - uncomfortable). These items were internally consistent

[2] The original scale consists of 35 items. The item "I take care of plants in the office" was dropped due to a lack of variance as it was not allowed to have plants in this office.

with Cronbach's alpha ranging from α = .79 to α = .90. Experienced lighting level was measured with three items about lighting level (artificial light and daylight) on the workplace, on the screen and in the office space from Hellinga and de Bruin-Hordijk [29]. The response scale ranged from (1) 'too little light' to (5) 'too much light' and the scale was internally consistent with alphas ranging from α = .72 to α = .84. Experienced disturbance of the artificial lighting was assessed with two items adopted from Hellinga and de Bruin-Hordijk [29]. The 5-point response scale ranged from (1) 'never' to (5) 'very often' and these items had an internal consistency of alpha ranging from α = .75 to α = .91. Experienced disturbance of daylight was measured with similar items. This scale was internally consistent with alpha ranging from α = .69 to α = .77. Satisfaction with the lighting was assessed with the question: 'How satisfied are you with the lighting at your workplace?' with response options ranging from (1) 'very dissatisfied' to (5) 'very satisfied'.

Job and work-related evaluations

Job-related questions concern evaluation of the work atmosphere, job satisfaction, commitment to the company, work diversity, decision authority and job demands. To assess work atmosphere, four evaluative statements were employed, such as 'The work atmosphere is good.' The response scale was a 5-point scale from (1) 'never' to (5) 'very often'. The internal consistency of the four statements ranged from α = .81 to α = .83. Three dichotomous (yes/no) statements were employed to assess job satisfaction ('I am satisfied with my job'), commitment to the company ('I feel committed to the company') and work diversity ('my work is diverse'), respectively. Decision authority and job demands were measured with two subscales of the Job Content Questionnaire [30]. Decision authority was assessed with three statements, such as 'I have freedom to make decisions about my job'. The subscale is internally consistent with alpha ranging from α = .64 to α = .69. Job demands were measured with four statements, such as 'My job requires I work fast'. This subscale had an internal consistency of alpha between α = .68 and α = .76. Both subscales had a 4-point response scale ranging from (1) 'totally disagree' to (4) 'totally agree'.

Work-condition related questions concerned the impression of the office environment, pleasantness of the indoor climate and satisfaction with the indoor climate. Impression of the office environment was assessed with nine adjectives, such as 'pleasant', 'orderly' and 'quiet' from Aries et al. [17]. The unipolar response options ranged from (1) 'not at all to' (5) 'extremely'. The internal consistency of the 9 adjectives ranged from α = .78 to α = .91. Pleasantness of the indoor climate was measured with two semantic differential adjective items (pleasant – unpleasant, comfortable - uncomfortable). This scale was internally consistent with alpha ranging from α = .84 to α = .92. To assess satisfaction with the indoor climate two items concerning satisfaction with the temperature and ventilation at the workplace were employed with response options ranging from (1) 'very dissatisfied' to (5) 'very satisfied'. This scale was internally consistent with alpha between α = .73 and α = .77.

Personal characteristics

Questions regarding personal characteristics concerned gender, age, light sensitivity, and mean number of working hours per week. Light sensitivity was measured with the items 'How much trouble do your eyes give when you are exposed to bright light?' and 'How much do you suffer from headaches when you are exposed to bright light?' on a 5-point scale from (1) 'not at all' to (5) 'extremely'. The reliability of this scale ranged from α = .73 to α = .78.

Procedure

In January, the lighting condition was dynamic for half of the participants (group A) and static for the others (group B). In the third week of this first month, all potential participants received an e-mail with a hyperlink to the questionnaire. A reminder was sent one week later. It took about 15 minutes to fill in the questionnaire. A Living Colors lamp from Philips was raffled every measurement period as an incentive for participants to complete the questionnaire. In February, the lighting condition was switched from dynamic to static and vice versa. In March, the lighting condition was again switched to the same lighting condition as in January. During the second and third measurement periods, the same procedure as in January was used.

RESULTS

To investigate the effect of lighting condition (dynamic vs. static lighting) on employees' well-being, health and performance, Linear Mixed Model analyses were performed on need for recovery, vitality, mental health, alertness, headache and eyestrain, sleep quality and subjective performance (separately), with Lighting condition and Month as fixed factors and participant number as random factor. Light sensitivity, impression of the office and work atmosphere were included as covariates[3].

The results showed that there was no significant effect of Lighting condition on need for recovery, vitality, mental health, alertness, headache and eyestrain, global sleep quality and subjective performance (all $F<1$, except alertness, $F=1.31$, NS). In Table 1, the F-statistics for Condition and Month are shown. Table 2 shows the estimated means for all dependent variables in both the static and the dynamic condition.

[3] We first assessed the Pearson's correlations between potentially confounding variables and dependent variables and added only those covariates that had significant correlations with the dependent measures for wellbeing, health and performance.

Table 1. Results linear Mixed Model analyses: F-statistics for Wellbeing, health and performance measures.

	Need for recovery		Vitality		Mental Health		headache & eyestrain		Alertness		sleep quality		Subjective performance	
	F	df	F	df	F	df	F	df	F	df	F	df	F	df
Lighting condition	.06	(1,167)	.08	(1,190)	.01	(1,179)	.01	(1,193)	1.31	(1,202)	.63	(1,151)	.35	(1,210)
Month	13.27**	(2,153)	.34	(2,169)	2.56†	(2,154)	.45	(2,172)	1.01	(2,180)	2.81†	(2,135)	1.19	(2,190)

* p < .05, ** p < .01 and † p < .10

Table 2. Estimated marginal means of wellbeing, health and performance measures.

	Dynamic		Static	
	M	*SD*	*M*	*SD*
Need for recovery	-0.76	0.05	-0.77	0.05
Vitality	3.59	0.04	3.58	0.04
Mental Health	4.10	0.03	4.10	0.03
Headache and eyestrain	1.53	0.03	1.53	0.03
Alertness	3.74	0.12	3.59	0.11
Sleep quality	4.98	0.18	4.84	0.17
Subjective performance	7.42	0.06	7.46	0.06

The factor Month did show an effect on need for recovery [F(2,153.0) = 13.27; p < .01]. Pair-wise comparisons indicated that workers' recovery needs were lower in January (M = -.95; SD = .77) than in February (M = -.64; SD = .71) and March (M = -.78; SD = .76) with p < .01 for both contrasts. There was no difference in recovery needs between February and March (p = .16). The effects of Month on remaining dependent variables did not reach significance.

We also performed Linear Mixed Model analyses with scales probing the subjective evaluation of the lighting as dependent variable, Lighting condition and Month as fixed factors, participant number as random factor, and light sensitivity, impression of the office environment and work atmosphere as covariates. The results of these analyses showed that Lighting condition had a significant effect on satisfaction with the lighting [F(1,211.5) = 5.16; p < .05]. Office workers were more satisfied with the lighting in the dynamic lighting condition (M = 3.69 and SD = .87) than in the static condition (M = 3.53 and SD = .91). In addition, Lighting condition had a significant effect on the experienced disturbances of artificial lighting [F(1,196.3) = 4.44; p < .05]. Unexpectedly, workers reported fewer disturbances of artificial lighting in the static condition (M = 1.71 and SD = .72) than in the dynamic lighting condition (M = 1.80 and SD = .78). Note that disturbances were measured on a 5-point scale, thus office employees in both conditions, on average never (1) or rarely (2) experienced disturbances of the artificial lighting. There was no significant effect of Lighting condition on experienced disturbances of daylight [F<1, NS]. In addition, the Lighting condition had no significant effect on the evaluation of pleasantness of the lighting [F>1, NS]. The effect of Lighting condition on experienced lighting level approached significance [F(1,247.2) = 3.01; p = .08]: indicating a trend for employees to evaluate the lighting as brighter in the dynamic lighting condition (M = 3.06 and SD = .48) than in the static condition (M = 2.98 and SD = .52). Table 3 reports the F-statistics for Lighting condition and Month concerning the subjective evaluation of the lighting; Table 4 reports the mean scores on all subscales for both experimental conditions.

Month had a significant effect on disturbances of daylight [F(2, 192.0) = 4.98; p < .01]. Pair-wise comparisons indicated that workers experienced more disturbances of daylight in January (M = 2.69; SD = .91) than in February (M = 2.54; SD = .91) and March (M = 2.52; SD = .82) with p < .05 for both contrasts. There was no significant difference between February and March concerning disturbances of daylight (p = .55).

Table 3. Results of Linear Mixed Model analyses: F-statistics of subjective evaluation of the lighting condition.

	Pleasantness lighting		Satisfaction lighting		Lighting level		Disturbances daylight		Disturbances lighting	
	F	df	F	df	F	df	F	df	F	df
Lighting condition	1.87	(1,242)	5.16*	(1,211)	3.01†	(1,247)	.93	(1,215)	4.44*	(1,196)
Month	1.09	(2,220)	.21	(2,192)	2.28	(2,223)	4.98**	(2,192)	1.31	(2,178)

* p < .05, ** p < .01 and † p < .10

Table 4. Estimated marginal means of subjective evaluations of lighting conditions.

	Dynamic		Static	
	M	*SD*	*M*	*SD*
Pleasantness lighting	3.66	0.06	3.55	0.06
Satisfaction lighting	3.73	0.07	3.57	0.06
Lighting level	3.06	0.04	2.97	0.04
Disturbance daylight	2.64	0.07	2.56	0.07
Disturbance lighting	1.82	0.06	1.69	0.06

DISCUSSION

We are investigating the effect of dynamic lighting compared to static lighting on workers' wellbeing, health and subjective performance in a longitudinal field study. In this paper, the results of the linear mixed model analyses on the data of the short-term groups are reported (first tranche). The results showed no significant difference in workers' need for recovery, vitality, sleep quality, mental health, headache and eyestrain, or subjective performance between the dynamic and static lighting condition, controlled for relevant personal, job and work-related characteristics.

Interestingly, in spite of us not finding the beneficial effects that were hypothesized, workers in the dynamic lighting condition did report being more satisfied with the lighting condition, although at the same time they reported more disturbances from the lighting than did workers in the static lighting condition.

Need for recovery showed a significant effect of month of measurement, with employees reporting a lower need in January than in February and March. A lower need for recovery indicates a lesser degree of attention fatigue and stress. This is in line with weather reports, indicating more hours of sun on the workdays during the measurement period in January than in February and March, but may also be related to the fact that most employees had taken time off in December on account of the holidays. The higher number of disturbances of daylight in January may also be explained by the fact that there were more hours of sun in the first measurement period than in the other two.

The question we now need to address is what conclusions could or should be drawn from these data. For this we must consider not only the data, but also the methodology. We had hoped to conduct the study in four consecutive months, running four full-month measuring periods. Yet instead we saw ourselves compelled to cut one period and shorten the remaining periods from four to three weeks. This unfortunately is the reality of doing field studies. However we did manage to uphold a sound experimental design. Also, considering the fact that in the questionnaires participants were always asked to reflect on the last two weeks, the procedure still worked well in the three-times-three-week period compromise that resulted.

Furthermore, we employed a range of measurements, none of which showed significant beneficial effects of dynamic lighting. All scales repeatedly showed good reliability and had been successfully used in earlier studies and although response rates were only modest, participant samples were still large enough to enable testing of these effects. Yet in spite of the robust design, methodology and procedure, we were not able to establish beneficial effects of dynamic lighting when compared to static lighting.

On the other hand, a few considerations caution us to not discard the potential of dynamic lighting just yet. First, a possible reason for the lack of expected findings is the substantial daylight contribution in the renovated building of our study, especially in combination with the daylight responsive lighting control. Dynamic lighting is said to be most effective in situations with low daylight contribution [31], so the building in this study – even if the study was performed during the darker months of the year - may not have been the best candidate for studying the effects of artificial lighting. Moreover, the dynamic pattern of the lighting itself my have attenuated the findings. As was already reflected in the introduction, there as yet exists only little research on dynamic lighting. The pattern employed in the current study employs fairly subtle changes, both in intensity and colour temperature, especially in comparison to changes outdoors, or manipulations applied in laboratory-based studies (e.g. [3,15,16,18,19,20]). These design choices have been based on state-of-the-art insights into human alertness curves, yet we are still far from fully understanding light's effects on humans' psychological and physiological states. The exact height of colour temperature and intensity of the lighting, the exact timing and shape of the curve and the range of wavelengths employed are all still under investigation.

We conclude that in the first tranche of this longitudinal research we have not been able to establish beneficial effects of dynamic lighting on individuals' need for recovery, vitality, sleep quality, mental health, headache and eyestrain, or subjective performance, although office workers did report higher satisfaction with dynamic than static lighting. Yet it is too early to discard the hypotheses and claims made about dynamic lighting altogether. Its effects may well emerge in more long-term applications, environments with limited daylight contribution, or when more pronounced, or differently shaped curves are applied in terms of intensity and/or colour temperature.

ACKNOWLEDGEMENT

We are grateful to Rijkswaterstaat, the Rijksgebouwendienst, Philips and Ariadne Tenner for their assistance and support during this project. We would also like to thank Martine Knoop for her comments on an earlier version of this paper.

REFERENCES

1. Begemann, S. H. A., van den Beld, G. J., & Tenner, A. D. (1997). Daylight, artificial light and people in an office environment, overview of visual and biological responses. *International Journal of Industrial Ergonomics, 20*, 231-239.
2. Knoop, M. (2006). Dynamic lighting for well-being in work places: Addressing the visual, emotional and biological aspects of lighting design. *Proceedings of the 15th international Symposium Lighting Engineering 2006* (63-74), Beld.
3. Rüger, M., Gordijn, M. C. M., Beersma, D. G. M., de Vries, B., Daan, S. (2006). Time-of-day-dependent effects of bright light exposure on human psychophysiology: comparison of daytime and nighttime exposure. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology, 290(5)*, 1413-1420.
4. Rüger, M. (2005). Lighting up the human circadian clock. Ph.D thesis, Groningen: University of Groningen.
5. Scheer, F. A., Buijs, R. M. (1999). Light affects morning salivary cortisol in humans. *Journal of Clinical Endocrinical Metabolism, 84(9),* 3395-3398.
6. van Bommel, W. J. M. (2006). Non-visual biological effect of lighting and the practical meaning for lighting for work. *Applied Ergonomics, 37(4)*, 461–466.
7. Rea, M. S., Figueiro, M. G., Bullough, J. D. (2002). Circadian photobiology: an emerging framework for lighting practice and research. *Lighting Research and Technology, 34(3),* 177-190.
8. Morita, T., & Tokura, H. (1998). The influence of different wavelengths of light on human biological rhythms. *Applied Human Science, 17*, 91-96.
9. van Bommel, W. J. M., van den Beld, G. J. (2004). Lighting for work: A review of visual and biological effects. *Lighting Research and Technology, 36(4),* 255-269.
10. Fleischer, S., Krueger, H., Schierz, C. (2001). Effect of brightness distribution and light colours on office staff, results of the 'Lighting harmony' project. *The 9th European Lighting Conference 'Lux Europa 2001'* (77-80), Reykjavik.
11. Mukea, H., & Sato, M. (1992). The effect of color temperature of lighting sources on the autonomic nervous functions. *The Annals of Physiological Antropology, 11,* 533-538.
12. Deguchi, T., & Sato, M. (1992). The effect of color temperature of lighting sources on mental activity level. *The Annals of Physiological Antropology, 11,* 37-43.
13. McColl, S. L., & Veitch, J. A. (2001). Full-spectrum lighting: a review of its effects on physiology and health. *Psychological Medicine, 31,* 949-964.
14. Veitch, J. A., & McColl, S. L. (2001). A critical examination of perceptual and cognitive effects attributed to full-spectrum fluorescent lighting. *Ergonomics, 44*, 255-279.
15. Viola, A. U., James, L. M., Schlangen L. J. M., Dijk, D-J. (2008). Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality, *Scandinavian Journal of Work, Environment and Health, 34(4),* 297-306.
16. Mills, P. M., Tomkins, S. C., Schlangen, L. J. M. (2007). The effect of high correlated colour temperature office lighting on employee wellbeing and work performance. *Journal of Circadian Rhythms, 5(2),* 2-10.
17. Aries, M. B. C. (2005). Human lighting demands, healthy lighting in an office environment. Ph.D thesis, Eindhoven: Eindhoven University of Technology.
18. Grünberger, J., Linzmayer, L., Dietzel, M., Saletu, B. (1993). The effect of biologically-active light on the noo- and thymopsyche and on psychophysiological variables in healthy volunteers. *International Journal of Psychophysiology, 15(1),* 27-37.
19. Badia, P., Myers, B., Boecker, M., & Culpepper, J. (1991). Bright light effects on body temperature, alertness, EEG and behavior. *Physiology and Behavior, 50(3)*, 582-588.
20. Kaida, K., Takahashi, M., & Otsuka, Y. (2007). A short nap and natural bright light exposure improve positive mood status. *Industrial Health, 45(2)*, 301-308.
21. Smolders, K. C. H. J. and de Kort, Y. A. W. (in press). Light up my day: A between-group test of dynamic lighting effects on office workers' wellbeing in the field. Proceedings of Lux Europa 2009, 9-11 September 2009, Istanbul.
22. http://www.knmi.nl/klimatologie/maand_en_seizoensoverzichten/index.html, retrieved 27 April 2009.
23. Smolders, K. C. H. J., de Kort, Y. A. W., Kaiser, F. G., Tenner, A. D. (2009). Need for Recovery in Offices: Behavior-based Assessment. Unpublished manuscript, in preparation.
24. Van Veldhoven, M., Broersen, S. (2003). Measurement quality and validity of the "Need for Recovery scale". *Occupational Environmental Medicine, 60(supplement 1)*, 3-9.
25. Bond, T. G., & Fox, C. M. (2001). *Applying the Rasch model: Fundamental measurement in the human science.* Mahwah, NJ: Erlbaum.
26. Van der Zee, K. I., Sanderman, R. (1993). *Het meten van de algemene gezondheidstoestand met de RAND-36, een handleiding.* Groningen: Rijksuniversiteit Groningen.
27. Åkerstedt, T., Gillberg, M. (1990). Subjective and Objective Sleepiness in the Active Individual, *International Journal of Neuroscience, 52(1)*, 29-37.
28. Buysse D. J., Reynolds C. F., Monk T. H. Berman S. R., Kupfer D. J. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(*2)*, 193–213.

29. Hellinga, H.IJ., de Bruin-Hordijk, G.J. (2008). The influence of daylight and view out on the visual comfort of workplaces. *Balkanlight 2008 Proceedings* (233-242), Ljubljana.
30. Karasek R., Brisson C., Kawakami N., Houtman I., Bongers P., Amick B. (1998). The job content questionnaire (JCQ): an instrument for internationally comparative assessments of psychosocial job characteristics. *Journal of Occupational Health Psychology, 3(4),* 322-355.
31. Schriek M.H.J. (2007). *Dynamic Lighting – Energy Savings by Use of Atypical Daylight Responsive Lighting Control*. Master Thesis, Eindhoven: Eindhoven University of Technology, Faculty Architecture.