Lighting in multi-user office environments

Citation for published version (APA):
van der Vleuten-Chraibi, S. (2019). *Lighting in multi-user office environments: improving employee wellbeing through personal control*. [Phd Thesis 1 (Research TU/e / Graduation TU/e), Built Environment]. Technische Universiteit Eindhoven.

Document status and date:
Published: 06/06/2019

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 04. Oct. 2023

Lighting in multi-user office environments

IMPROVING EMPLOYEE WELLBEING THROUGH PERSONAL CONTROL

Sanae van der Vleuten-Chraibi

Bouwstenen 271

Lighting in multi-user office environments

Improving employee wellbeing through personal control

Sanae van der Vleuten-Chraibi

The work described in this thesis has been carried out at the Philips Research and Signify Laboratories in Eindhoven, the Netherlands. This research was performed within the Spark Impuls II program within the framework of strategic joint research on Intelligent Lighting between TU/e, Koninklijke Philips N.V., and Lighting (later Signify N.V.).

This work was supported by the Sound Lighting research line of the Intelligent Lighting Institute (ILI) at Eindhoven University of Technology and the Lighting Applications research program in Philips Lighting Research (later Signify N.V.).

ISBN: 978-90-386-4774-6

A catalogue record is available from the Eindhoven University of Technology Library

An electronic copy of this thesis in PDF format is available from the TU/e library website (http://repository.tue.nl)

Lighting in multi-user office environments

Improving employee wellbeing through personal control

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven,
op gezag van de rector magnificus prof.dr.ir. F.P.T. Baaijens,
voor een commissie aangewezen door het College voor Promoties,
in het openbaar te verdedigen
op donderdag 6 juni 2019 om 13:30 uur

door
Sanae van der Vleuten-Chraibi
geboren te Haaksbergen

Dit proefschrift is goedgekeurd door de promotoren en de samenstelling van de promotiecommissie is als volgt:

voorzitter: prof.dr.ir. T.A.M. Salet
1e promotor: prof.Dr.-Ing. A.L.P. Rosemann
2e promotor: prof.dr.ir. E.J. van Loenen
copromotor: prof.dr.ir. M.B.C. Aries (Jönköping University)
leden: prof.dr. S. Altomonte (Université Catholique de Louvain)
prof.dr. H.S.M. Kort
prof.dr.ir. J.H. Eggen
prof.dr.ir. Y.A.W. de Kort

Het onderzoek of ontwerp dat in dit proefschrift wordt beschreven is uitgevoerd in overeenstemming met de TU/e Gedragscode Wetenschapsbeoefening.

Contents

Summary

Summary

Spending a large majority of our time indoors makes the indoor environmental conditions important determinants of our satisfaction and wellbeing. Over the last decades, lighting has established itself as a recognized influencer of people's wellbeing in living and working environments. While poor design can cause discomfort, the right implementations can elevate satisfaction, improve mood, and influence performance. Recent years, a shift in approaches to office design could be observed. Employers are increasingly realizing that people represent not only their highest cost but also their greatest asset. This resulted in workplace design as a means to attract talent, retain high-value employees, and enhance organizational performance. The office as functional workspace has started giving way to spaces designed to engage and inspire. An engaging workplace fosters creativity, encourages innovation, and, maybe most importantly, increases commitment. These insights have boosted the application of open office environments. The shared character of the open office does, however, create challenges to cater to the individual's wellbeing in these multi-user spaces.

In this thesis, research is presented exploring how wellbeing in the modern open plan office can be improved, by offering satisfying lighting environments through personal control (Chapter 2). Wellbeing is herein assessed through the users' satisfaction with environmental conditions, their mood, and the occurrence of conflict between users. In a series of studies, strategies for improvement of the personal control proposition are explored, being user profiling (Chapter 3), the influence of wall brightness (Chapter 4), and noticeable and acceptable dimming of lighting (Chapter 5).

Users can greatly benefit from experiencing their individual preferred lighting, with additional benefits for personally controlling it. In the first study of this thesis, presented in Chapter 2, personal control of the general lighting system was evaluated in a longitudinal field study in an open office environment. In the study, reference conditions without control, as well as control conditions with consensus control were evaluated. The study showed that consensus control in an open office improves the satisfaction of individual users with the quantity and quality of light, compared to the reference situation with a fixed average work plane illuminance. When offered controls, the average preferred illuminance values were lower than the values currently recommended by standards. Even though the controllable light was shared, the consensus among users did result in an improved lighting environment for the majority of the users and did not introduce a negative effect on the environmental satisfaction or the mood of the office users.

To lower the probability of conflict between users and to secure the users' comfort, a method is proposed to model users' lighting preference profiles based on their control behaviour with the lighting system. In the second study, data of two field experiments was used to profile users based on their system interactions (Chapter 3). The study showed that users can be profiled based on their activeness, tolerance, dominance and lighting preferences. The profiles, determined with the proposed model, were validated using questionnaire and interview data of both studies. By knowing user lighting preference profiles, the satisfaction of users with lighting conditions can be improved by 1) Predicting the probability of conflict between the users in the same control zone and facilitate in making consensus choices; 2) Allocating users to different zones that match their profiles, by having information regarding conflict, thus improving users' satisfaction with lighting conditions; 3) Offering lighting conditions that meet the preference profiles of the

users using a weighted combination of user profiles; and 4) Triggering submissive, inactive users to express their preference.

Interview results of the first study suggested that, when provided with controls, users do not only select a preferred task illuminance to meet personal requirements for their visual task; they furthermore see in the personal control a means to set a visually preferred lighting environment. In the third experiment, a laboratory study was set up to evaluate the influence of the luminance of the wall in the visual field of the users on their selected desk illuminance (Chapter 4). In this study, the uniformity and luminance levels of the wall were evaluated for their effect on selected desk illuminance levels within and between individuals. Wall lighting conditions with three different average luminance levels were evaluated, all applied with a non-uniform distribution and a more uniform distribution. The results indicated that high maximum luminance values of the wall lead to lower selected desk illuminance levels and that high minimum wall luminance values creating little contrast between the task and the background, lead to higher selected desk illuminance levels. The start-point for dimming of the task lighting had a significant influence on users' selected task illuminance levels.

Conflict can also occur when co-workers are disturbed by experiencing light changes triggered by others. Interview results of the first study suggested that co-workers' acceptance of dimming increased with an increasing fading time. In the fourth study, two laboratory experiments were conducted evaluating noticeability and acceptance of light changes when applying occupancy-based dimming on desk level (Chapter 5). These experiments were conducted with participants of two age groups (18-30 years and 30-50 years). A single luminaire above a colleague's desk, within the users' visual field, was dimmed from low to high, and vice versa. The results confirmed that co-worker's acceptance increased with an increasing fading time for dimming. When dimming with a fading time close to zero, less than 60% of the population rated the conditions as acceptable. Applying occupancy-based dimming on desk level while using a fading time of at least 1.71 s, overall acceptance of at least 70% was achieved. The results of acceptance were similar for both examined age categories, but noticeability did show some difference between the age groups. Dimming with a fading time of almost 5 s or higher was not noticed by at least 80% of the population with a typical office age, while the examined student population showed a slightly more critical noticeability threshold, of 75% of the students not noticing the light change.

In this thesis, research is presented showing that in shared office spaces, like open plan offices, personal control over lighting can improve the users' appreciation of office lighting. The proposition of personal control can be further optimized when the preferences of users in the office are considered and integrated in the behaviour or feedback of the system. By careful consideration of the brightness of the office walls as well as the speed by which dimming is applied, the risk of conflict occurrence can be limited. Technological developments allow for state-of-the-art systems, that can support building owners or employers in optimizing their buildings, to increase efficiency and limit costs. To utilize these advanced systems to their full potential, it is important to keep considering and consulting the users of the buildings. Designing for optimal user experience and using user experience information in systems, allows for improvement and optimization of systems, as well as for users' wellbeing through satisfying environments.

Samenvatting

Samenvatting

Kantoormedewerkers brengen een groot deel van hun dag door in de gebouwde omgeving. Daardoor heeft ons binnenmilieu een grote invloed op ons algemene welzijn. Dit belang is reeds decennia geleden erkend door het vaststellen van normen en richtlijnen ter voorkoming van discomfort middels o.a. voldoende verlichting in gebouwen. Vandaag de dag is er een groeiende trend waarneembaar waarin ontwerpen niet alleen discomfort trachten te elimineren, maar een optimum in welzijn proberen te bieden. De werkplek ondergaat een transitie van een functionele ruimte naar een prettige plek, die beoogd te inspireren en waar welzijn wordt gelinkt aan verhoogde creativiteit en innovatie. De werkplek wordt daarmee vaker ingezet ten gunste van het imago van een organisatie en om talentvol personeel aan te trekken en te behouden. Deze trend zorgt voor een opmars van de moderne open kantoor concepten waar, naast brainstorm, break-out en focus rooms, een groot deel bestaat uit open kantoortuinen die kleine tot zeer grote groepen medewerkers huisvesten. Deze gedeelde ruimten introduceren echter uitdagingen wat betreft het optimaliseren van het welzijn van de individu.

Dit proefschrift presenteert de resultaten van een onderzoek naar hoe het welzijn van werknemers in open kantoortuinen verbeterd kan worden door het bieden van de mogelijkheid om individueel de verlichting in te stellen, ook wel *personal control* genoemd. In een serie van 2 velstudies (Hoofdstuk 2 en 3) en 2 laboratoriumexperimenten (Hoofdstuk 4 en 5) is *personal control* geëvalueerd en zijn optimalisatie mogelijkheden geëxploreerd. Hoofdstuk 2 rapporteert de eerste veldstudie, waarin participanten *personal control* over de plafondverlichting is geboden, gebruikmakend van individuele interfaces. Met deze interfaces konden gebruikers een zone van de verlichting bedienen, bestaande uit twee armaturen. Elke zone werd gedeeld door twee of drie medewerkers, resulterende in *consensus control.* Deze situatie is vergeleken met een referentie situatie zonder *personal control*. Welzijn is in deze studie subjectief geëvalueerd met behulp van comfort, tevredenheid en conflict vragenlijsten, ondersteund met interviews. De studie heeft aangetoond dat de tevredenheid van de gebruikers met betrekking tot de kwantiteit en kwaliteit van verlichting verbeterde in de situatie met *consensus control* ten opzichte van de referentie situatie zonder control. *Consensus control* zorgde tevens voor lager ingestelde horizontale verlichtingssterktes dan volgens normen is voorgeschreven. Ondanks het moeten delen van de bedienbare verlichting, gaf het grootste deel van de gebruikers een voorkeur aan de situatie met control, en heeft control geen negatieve impact gehad op de algemene tevredenheid met het binnenmilieu of de emotionele staat van participanten.

De studie bracht echter wel enkele gevallen van conflict aan het licht. Deze hebben geleid tot de exploratie van strategieën die mogelijk het bieden van *personal control* kunnen verbeteren, bestaande uit; integratie van voorkeursprofielen van gebruikers in de bediening van licht (Hoofdstuk 3); beïnvloeden van het keuzegedrag van gebruikers door de helderheid van de wanden in het visuele veld aan te passen (Hoofdstuk 4); optimalisatie van de dimsnelheid om de acceptatie van licht veranderingen te verhogen (Hoofdstuk 5).

Hoofdstuk 3 presenteert het model dat is opgesteld voor het bepalen van de gebruikersprofielen. Het model maakt gebruik van interactiedata van gebruikers met het verlichtingssysteem, verkregen in de veldstudies. Analyse van de data heeft geleid tot het identificeren van vier parameters die samen een profiel omschrijven met betrekking tot verlichtingsvoorkeur en gedrag. Deze parameters bestaan uit de

verlichtingssterkte voorkeur van de gebruiker, zijn tolerantie betreft afwijkingen daarvan, de frequentie van activiteit met de interface, en de dominantie waarin zijn voorkeur profileert in de zone. De toegekende profielen zijn gevalideerd aan de hand van de subjectieve data verkregen middels vragenlijsten en interviews. Wanneer in een werkomgeving de profielen van de gebruikers bekend zijn, biedt dit mogelijkheden de tevredenheid in de gedeelde werkomgeving te verbeteren middels 1) het voorspellen van mogelijk optredend conflict, waarop mensen geïnformeerd kunnen worden om een weloverwogen keuze te maken; 2) gebruikers begeleiden naar een werkplek die aansluit op hun profiel; 3) (semi-) automatisch licht condities bieden, gewogen naar de aanwezige gebruikersprofielen; 4) het herkennen van inactieve gebruikers wiens voorkeur niet of nauwelijks profileert, en deze gebruikers aanzetten tot het uitdrukken van hun voorkeur.

De interview resultaten van de eerste veldstudie gaven aan dat wanneer mensen *personal control* wordt geboden, ze deze niet alleen gebruiken voor het instellen van de gewenste verlichtingssterkte van de taak, maar hierin ook een middel zien hun geprefereerde verlichtingsomgeving in te stellen. Bijvoorbeeld door de taakverlichting hoger in te stellen, wanneer de wens is een helderdere ruimte te creëren. Dit was aanleiding om in een derde experiment de invloed van de helderheid van de wand op de geselecteerde taakverlichting te evalueren. Hoofdstuk 4 rapporteert de laboratorium studie waarin zes scenario's zijn getest, bestaande uit drie verschillende gemiddelde wand luminanties, uitgevoerd met een non-uniforme en een meer uniforme lichtverdeling. De gebruiker werd gevraagd middels een interface zijn licht voorkeur op de taak in te stellen. Dit werd voor elk scenario gedaan vanuit drie verschillende startwaarden van de te bedienen plafondverlichting. Een hoge maximale luminantie van de wand (bij een meer non-uniforme lichtverdeling) leidde tot lager geselecteerde taak verlichtingsniveaus, en een hoge minimale luminantie van de wand (bij een meer uniforme lichtverdeling), met weinig contrast tussen het beeldscherm en de achterwand, leidde tot hoge geselecteerde taak verlichtingsniveaus. De startwaarde van waaruit de gebruiker zijn voorkeur kon instellen had tevens een significant effect op de ingestelde waarde, met kleinere verschillen tussen gebruikers bij de laagste startwaarde.

Conflict kan ook ontstaan wanneer medewerkers gestoord worden door lichtveranderingen in hun visuele veld, veroorzaakt door mede kantoorgebruikers. De interview resultaten van de eerste veldstudie suggereerden dat de acceptatie van lichtveranderingen groter wordt naarmate er meer tijd voor wordt genomen; lagere dimsnelheid. Hoofdstuk 5 rapporteert een vierde studie waarin twee lab experimenten zijn uitgevoerd waarin de waarneembaarheid en acceptatie van lichtveranderingen is geëvalueerd (Hoofdstuk 5). In deze experimenten is de strategie van 'occupancy-based' dimmen geëvalueerd, waarbij de verlichting van een werkplek omlaag wordt gedimd wanneer deze werkplek niet in gebruik is, en omhoog wanneer bezet. In de experimenten is deze strategie gesimuleerd middels een acteur die op geïnstrueerde momenten de werkplek verliet dan wel betrad, gepaard gaande met veranderingen van de plafondverlichting boven zijn werkplek. Deze veranderingen van de plafondverlichting werden met verschillende dimsnelheden uitgevoerd. Participanten, aan andere werkplekken, voerden een gesimuleerde kantoortaak uit en evalueerden de waarneembaarheid en acceptatie van de veranderingen. Het eerste experiment is uitgevoerd met een studentenpopulatie (18-30 jaar), het tweede met een 'kantoorpopulatie' (30-50 jaar). De resultaten bevestigden dat de acceptatie van lichtveranderingen in het visuele veld groter wordt bij een langere dim tijd. Wanneer dimmen werd uitgevoerd met een dim tijd van bijna 0 seconden, ervaarde minder dan 60% van de participanten de condities als acceptabel. Dimmen met een dim tijd van minimaal 1.71 seconden, resulteerde in acceptatie door minimaal 70% van de participanten. Dimmen met een dim tijd van minimaal 5 seconden, werd niet opgemerkt door 75% van de studentenpopulatie en niet opgemerkt door meer dan 80% van de kantoor populatie.

Dit proefschrift presenteert onderzoek naar de impact van *personal control* van licht op het welzijn van gebruikers in multi-user kantoren. Het laat zien dat in gedeelde kantoren, zoals open kantoortuinen, *personal control* de tevredenheid van medewerkers met de verlichting kan verbeteren. De propositie van *personal control* kan verder geoptimaliseerd worden wanneer de voorkeuren van gebruikers worden meegenomen en geïntegreerd worden in het gedrag van het verlichtingssysteem, dan wel de feedback die het systeem teruggeeft aan de gebruiker. Het risico op conflict tussen kantoorgebruikers kan verkleind worden door zorgvuldig de helderheid van de wanden van de ruimte en de snelheid van het dimmen te kiezen. Technologische ontwikkelingen zorgen voor systemen, die gebouweigenaren of werkgevers kunnen ondersteunen bij het optimaliseren van hun gebouwen, om de efficiëntie te verhogen en de kosten te beperken. Om deze geavanceerde systemen optimaal te benutten, is het belangrijk om de gebruikers van de gebouwen in beschouwing te blijven nemen en ze te raadplegen indien nodig en mogelijk. Het gebruiken van informatie over gebruikerservaringen in systemen, kan zorgen voor verbetering en optimalisatie van systemen, en kan positief bijdragen aan het welzijn van gebruikers door het bieden van een prettige werkomgeving.

Chapter 1

1. Introduction

Our experience of the environment we reside in is influenced by many factors. It is affected by its architectural design and its interior, but also the physical conditions. Lighting is one of these physical conditions and can transform spaces from cosy and welcoming to cold and unwelcoming. It can do that while we are conscious of its effects, or without our awareness. Over the last decades, lighting has established itself as a recognized influencer of our wellbeing in living and working environments. While poor designs can cause discomfort and unpleasantness, the right implementations can elevate our satisfaction and positively contribute to our wellbeing.

With the uprising of the knowledge economy, employers increasingly realize that people represent not only their highest cost but also, and above all, their greatest asset. Companies desire environments which foster creativity and innovation, but maybe even more importantly, increase the commitment of their employees. Finding and retaining talent and enhancing the workforce's efficiency are top priorities when pursuing organizational productivity. Strengthened from the field of human resources, improving engagement has become a recognized and powerful tool to get the best out of the workforce. Studies by companies as Steelcase and Gallup report that organizations with high employee engagement levels score high with regard to their organizational productivity (Harter, Schmidt, Agrawal, Plowman, & Blue, 2016; Steelcase, 2016). Employee engagement defines the emotional commitment the employee has to the organization and its goals. Engaged employees are involved and use discretionary effort when performing their job. More than one-third of workers, in what Steelcase defines as the world's 17 most important economies, show to be disengaged (Steelcase, 2016). The data of the Steelcase study shows that workers who are highly satisfied with various aspects of their workplace, such as its size, furniture, lighting, ambient noise level and temperature, also demonstrate higher levels of engagement (13% of global workers), while highly dissatisfied employees are highly disengaged (11% of global workers). This positive correlation between engagement and workplace satisfaction indicates that optimizing the environment can be an important tool for organizations to improve engagement. The data also shows that highly engaged employees score their organizations high for considering their wellbeing, which is in line with the results of Leesman (2016), reporting environmental satisfaction to be directly related to the health and work productivity of office workers.

These insights are boosting the transition of office spaces from functional desks to perform tasks, to environments of greater importance. In recent years, the deployment of different workplace design strategies could be observed, all with the similar objective to support engaging and productive environments and workforces. Workplace strategies like Activity Based Working and New Ways of Working (Leesman, 2016) intend to provide employees with purposefully designed settings to best support the many different activities that are undertaken in a workplace. Claimed benefits, include healthier, more engaged and motivated employees and a flexible physical infrastructure to easily adapt to business changes. These claimed benefits have increased the adoption rate of the modern open plan office space. Negative user experiences of open plan offices are however frequently reported. Downsides of open plan spaces are then put next to the benefits of private offices. Nonetheless, nine out of ten of the highest performing workplaces are either fully, or extensively open plan (Leesman, 2017).

With the growing popularity of wellbeing focussed strategies, market awareness regarding the role of wellbeing in productive environments has also increased. Strategies such as biophilic design (a philosophy that encourages the use of natural systems and processes in the design of the built environment (Gillis & Gatersleben, 2015; Kellert & Calabrese, 2015)), and building certifications such as the WELL building standard, focused on developing healthy buildings (International WELL Building Institute, 2016), emphasize the health and wellbeing in general of office users. Buildings have far-reaching impact on human wellbeing and with that indirectly on organizational productivity (Heerwagen, 1998). Affecting the user through different paths and mechanisms, the organization's productivity is influenced by i.e. staff turnover, retention rates and absenteeism. Figure 1 shows a simplified visualization of the relations between building, user, and organization (de Vries & Van der Vleuten-Chraibi, 2019).

Lighting is one of the buildings' workplace characteristics. In this thesis, research is presented, addressing the role of lighting control in increasing wellbeing in the modern open plan office. In this Chapter, the parameters included in the here used meaning of wellbeing will be introduced, the importance of wellbeing in offices will be discussed, and the lit office environment will be reviewed for its impact on wellbeing directly and indirectly. After providing an overview of the benefits of personal control, the open office challenge of personal control will be introduced, leading to the hypotheses of this thesis.

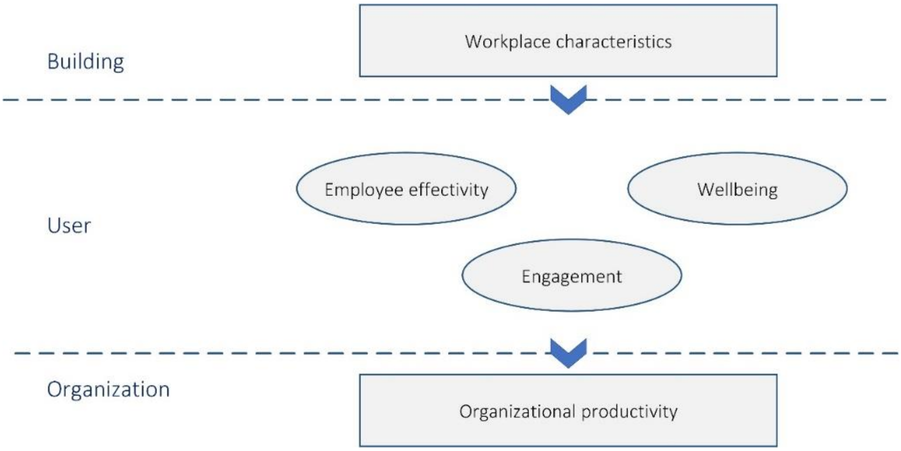


Figure 1. Reported relations between building, user, and organization. Workplace characteristics, influencing users, which through different paths and mechanisms affect organizational productivity.

1.1. Wellbeing in office environments

In this research the extensive term 'wellbeing' is used to refer to the users feeling well, their 'being well' as the term literally states. Wellbeing is a term and subject with growing attention, used in different ways. Sometimes it is put next to terms as health and comfort, sometimes it includes these aspects in its meaning. In an analysis it was tried to master the complexity of wellbeing (de Vries & Van der Vleuten-Chraibi, 2019). The Oxford dictionary (Simpson & Weinier, 1989) describes wellbeing as 'the state of being comfortable, healthy or happy'. Based on literature one could challenge the need to revise this definition in a more comprehensive model to capture the complexity. But it can also be argued that relevant parameters are directly or indirectly still linked to these core components 'comfort, health, and happiness'. In this research the interlinked components comfort, health, and happiness are included when addressing wellbeing. These components can also be recognized in Vischer's 'Habitability pyramid' (Figure 2), which describes a model wherein occupant satisfaction and wellbeing are based on three hierarchically related categories named physical, functional and psychological comfort (Vischer, 2007). Physical comfort includes the basic human needs without which a building is uninhabitable. These needs are in general addressed by applying building codes and standards to the building design. Functional comfort is defined through ergonomic support for users' performance of work-related tasks and activities. This includes ergonomic furniture and enclosed spaces for collaborative work, but also appropriate lighting for the task, ensuring the functional comfort of the users. Psychological comfort results from feelings of belonging, ownership and control over the workspace. The model of Vischer hypothesizes that, although weakness in one category can be compensated for by strength in another, optimal environmental support for work performance is most likely achieved when all three are well addressed.

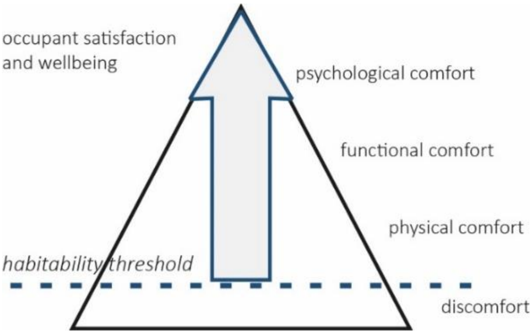


Figure 2. 'Habitability' pyramid (Vischer 2007).

Wellbeing is sometimes directly evaluated, but often also through selected sub-components (comfort, health, happiness) or interlinked parameters, like satisfaction with the environment, mood, or sleep. In this research 'satisfaction' is often used to assess the users evaluation of the environment. It is assumed that an environment evaluated as satisfying by a user, will contribute positively to his wellbeing by affecting his comfort, health, and/ or happiness. The size of the impact on the individual sub-components comfort, health, and happiness is not assumed to be always equal.

In a survey study performed under 1036 employees, various components of wellbeing were assessed and analysed for their links to real-estate factors (Baričič & Salaj, 2014). The survey showed real-estate factors, like workplace design, to have an impact on the satisfaction of employees and a significant effect workplace satisfaction on overall health assessments of employees was established from the analyses. As we spend a large majority of our time indoors, the indoor environmental conditions make important determinants of our satisfaction and wellbeing. While in traditional offices furniture, privacy and general facilities are high influencers of satisfaction, in the earlier introduced New Way of Working offices (Leesman, 2016), satisfaction of employees is reported to be highly influenced by climate, décor, cleanliness and office leisure (Appel-Meulenbroek, Kemperman, van Susante, & Hoendervanger, 2015). Based on research of Al Horr and colleagues (2016), eight physical factors of the building could be identified, which affect occupant satisfaction in an office environment, being indoor air quality and ventilation, thermal comfort, lighting and daylighting, noise and acoustics, office layout, biophilia and views, look and feel, and the location and amenities of the office. From an evaluation with 333 office employees from ten office buildings, Aries et al.

(2010) reported a relation between environmental satisfaction and employees' comfort ratings. In their study, they found that the more positive an employee is about his environment, the less discomfort he or she reports. Perceived comfort was shown to be strongly influenced by several personal, social, and building factors, but relationships are complex (Bluyssen, Aries, & van Dommelen, 2011).

Besides its effect on satisfaction and wellbeing, the physical environment also plays an important role on the employee's and organization's effectiveness. Open-plan office occupants who are more satisfied with their environments were found to be more satisfied with their jobs (Veitch, Charles, Farley, & Newsham, 2007). Bergs reported that when respondents state a higher degree of dissatisfaction, a parallel loss of productivity occurs (expressed by respondents' lost work time per week). This was particularly the case for dissatisfying lighting, followed by comfortable temperature and air quality (Bergs, 2002). Advantages in terms of health and wellbeing, besides being important for the workers themselves, were also shown to lead to better work performance, fewer errors, better safety, and lower absenteeism (van Bommel & van den Beld, 2004). Based on a survey study at 21 low energy offices assessing the relationship between self-reported productivity and perceived comfort, feeling healthier in the building was found to account for 61% of the variation in the measured increase in perceived productivity (Gupta, Cudmore, & Bruce-onuah, 2016). Environmental stress caused by inadequate indoor environmental quality, was found to reduce the cognitive capacity for work but also the rate of work (i.e., by reducing motivation) (Lamb & Kwok, 2016). This is supported by findings from survey data of 1500 employees, in which a direct correlation was shown between the employees' comfort levels and their work engagement (Feige, Wallbaum, Janser, & Windlinger, 2013). In their study, work engagement was defined as a "positive, fulfilling, work-related state of mind that is characterized by vigour, dedication, and absorption". According to the authors this demonstrates that high user comfort can reduce turnover rates of employees.

1.2. The impact of the lit environment

Different studies are published reporting beneficial effects of daylight exposure on wellbeing of office employees, and also the role of artificial lighting on wellbeing is getting more recognized (Altomonte, 2009; Boubekri, Cheung, Reid, Wang, & Zee, 2014; Boyce, Hunter, & Howlett, 2003; Elzeyadi, 2011; Figueiro & Rea, 2014; Shishegar & Boubekri, 2016). This is supported by the inclusion of lighting as one of the ten concepts of the WELL-building standard (International WELL Building Institute, 2016). Reported impacts include both image forming effects of light, such as the appreciation of the office environment, and also non-image forming effects, like alertness. In this section an outline will be given of reported effects of lighting. Some studies report a direct impact of lighting on wellbeing, others through mediating variables like satisfaction ratings, mood, or sleep and alertness ratings.

1.2.1. Wellbeing

Wellbeing is defined in this thesis as a state of feeling healthy, happy, and comfortable. In literature, a wide range of studies can be found reporting effects of lighting in office applications on wellbeing in general, or on its here used sub-components: comfort, health or happiness. In the post-occupancy evaluation study performed by Baird et al. (2010), a moderate to strong correlation was shown between positive overall lighting perception ratings of users and the factors productivity, health, and overall comfort. However, this was mainly caused by the users' ratings of natural lighting. In the study performed by Veitch and colleagues (2011), wellbeing was assessed through multiple elements, and linked to engagement. The study showed that people who appraise their lighting as good will also be in a more pleasant mood, be more satisfied with the work environment, and be more engaged in their work. Akashah et al. (2015) in turn correlated lighting to health and comfort through physical symptoms like tired or dry eyes, and blurred vision using a post-occupancy evaluation, without further specifying the underlying causes.

Fleischer and colleagues (2001) measured the highest subjective wellbeing of users when systems which alter depending on the weather were applied, using direct lighting (100% downward component) for an overcast sky and indirect lighting for a clear sky. The lowest wellbeing was measured with time-dependant distributions of direct and indirect lighting. In a cubicle study performed in the US, user comfort of four lighting installations was measured and compared. A lighting system with direct and indirect lighting was experienced as more comfortable than a system with only direct lighting (by approximately 80% vs approximately 70% of the participants), with further increase in comfort associated with personal control (Boyce et al., 2006a; Veitch, Newsham, Boyce, & Jones, 2008). Fostervold and Nersveen (2008) state however, that evidence supporting the advantage of indirect lighting in offices is limited. In their study, a significantly lower job stress severity level was measured for lighting schemes providing direct lighting, compared to systems using combinations of direct and indirect lighting. Apart from the possible effect for perceived severity of job stress, their study did not indicate that varying proportions of indirect and direct lighting affect health, wellbeing in general, or cognitive performance of employees working in ordinary office environments.

In a study performed by Akashi and Boyce (2006), the effect of ambient lighting reductions was explored by making modifications to the regular array of ceiling recessed luminaires, while maintaining task lighting through under-shelf units. After the initial adaptation period, office workers were generally satisfied with the lower level of ambient lighting, which was decreased from 500 to 360 lx. Some dramatic short-term effects were observed, but these were ascribed by the authors to the dislike of change in their working environment.

In the study of Geerdinck and Schlangen (2006), a lighting system using a high correlated colour temperature (CCT) was introduced in the office. The CCT characterizes the colour properties of white light sources, and is a measure for the colour appearance of the light emitted by the light source (Boyce, 2003). The lighting system with a CCT of 17000K (700-800 lx) was well accepted and appreciated by the office users, with 86% of the office workers wanting to keep the installation after the 3-week intervention. The authors reported a potential to impact health and performance by the introduced lighting system but could not quantify this impact with the standardized health and wellbeing surveys used. In other studies, high CCT conditions resulted in lower comfort and satisfaction ratings. In the study of Wei et al. (2014) satisfaction and visual comfort were assessed comparing luminous conditions of 3500K and 5000K. Without daylight access, the conditions showed similar visual comfort, while with daylight access, luminous conditions of 5000K resulted in lower satisfaction, and reduced visual comfort. In the study of Iskra-Golec et al. (2012), the participants rated the blue-enriched condition of 17000K as slightly more unpleasant compared to the warm light condition of 4000K. The study did show differences in comfort ratings of the lighting over the day which suggests a higher sensitivity to the brightness of blue-enriched white light in the morning and in the afternoon compared to midday.

Assessing the effects of dynamic lighting, De Kort and Smolders (2010) found in their field study that office workers were more satisfied with the lighting when exposed to a dynamic lighting condition compared to a static condition. This is in line with statements of Van Bommel and Van den Beld suggesting that it can be beneficial for the employees' wellbeing to be able to adapt both the level and the colour temperature of the lighting (van Bommel & van den Beld, 2004). Workers in the study of De Kort and Smolders (2010) however reported fewer disturbances of artificial lighting in the static condition than in the dynamic lighting condition. Disturbances were measured by experienced hindrance from artificial lighting on a 5-point scale, resulting in 'never' in the static condition and 'rarely' in the dynamic condition. In their study, no significant differences were found in workers' need for recovery, vitality, sleep quality, mental health, or headache and eyestrain. The authors did note that differences between the dynamic and static condition in this field study could however been limited due to daylight. In a visual comfort study, Kim and Kim (2007b) evaluated visual comfort of an automatic system providing dynamic lighting. Feelings of eye fatigue, distraction and annoyance were the main contributors to visual comfort. In their study they found that with a higher desktop illuminance, the subjects reported less annoyance when the same illuminance change was made. A 500 lx task illuminance condition allowed for a maximum illuminance fluctuation of 200 lx, while a 650 lx task illuminance condition allowed for a maximum illuminance fluctuation of 250 lx.

1.2.2. Appreciation of the lit environment

Employees' appreciation of the environment is repeatedly reported to be affected by lighting conditions. In an evaluation performed by Manav, an illumination level of 2000 lx was preferred over 500 lx regarding impressions of comfort, spaciousness, brightness and saturation evaluation (Manav, 2007). In a post-occupancy evaluation performed in 14 different buildings in California USA, less extremely deviating illuminance values were assessed, but results showed the same pattern (Choi & Moon, 2017). The lighting conditions with higher work surface illuminance levels (450-525 lx) were rated more satisfying compared to the lower illuminance levels (300-450 lx) recorded at workstations that received negative satisfaction responses. Dangol et al. (2013) performed user acceptance studies with lighting conditions with varying CCT, desk illuminance, and spectral power distribution (described by the strength of each wavelength of light produced by the light source). In each condition the observers' preference, naturalness of objects and hands, and colourfulness was assessed. The observers preferred an illuminance value of 500 lx over 300 lx at both 4000K and 6500K. A light level of 300 lx was rated as uncomfortable at both 4000K and 6500K. The observers felt that objects appeared more natural and more colourful under a light level of 500 lx compared to a light level of 300 lx. This is in accordance with the work of Boyce and Cuttle (1990), who found that with an increased light level the lighting of the room becomes more natural, more colourful, more pleasant, more comfortable, clearer, brighter, more friendly, more warm and more uniform.

Veitch (2001) reported that people use luminance distributions as a basis for judgements about the appearance of a space. The dominant dimensions of these judgments appear to be brightness (or lightness), and interest (variability). This is in line with statements of Van Bommel and Van den Beld (2004), indicating that controlled brightness of the surfaces that form the physical limits of the space, such as walls, floor and ceiling to be important with regard to the atmosphere and the visual impression of the workplace. The brightness of these surfaces determines to a large extent how the total space is experienced. Kirsch and Völker (2014) found 'lightness' and 'attractiveness' to be two different assessments. Illuminance of the task surrounding areas was reported to not affect the ratings of visual lightness of a room, while ratings of room attractiveness were influenced by the illuminance of the task surrounding areas, as well as the illumination of the walls. Illumination of walls was found to have a great impact on the users' perceived lighting quality and made the office appear brighter and more attractive. Ooyen et al. (1987) reported, wall luminance to contribute most to the way a room is experienced. With an increasing wall luminance, the room was felt to be more stimulating, which is supported by De Vries et al. (2018). Loe et al. (1994) also expressed the importance of considering luminance contrast and the average vertical luminance in the field of view, stating its importance for offering a lit environment that is 'light' and ' visually interesting'. The average luminance of the walls, was also shown by Carter and colleagues (1994b) to have an influence on the assessment of relative brightness of the space. Assessment of acceptability of brightness and pleasantness showed to increase with increasing luminance within the 40° field of view band for installations in which the lighting was even distributed. Their study showed that conditions with lighting installations rated as more even were also rated more acceptable by the users, with pleasantness following the same trend. The most uneven installations were rated as most unpleasant and least acceptable (Carter et al., 1994b). The evaluation of Cetegen et al. (2008) using high dynamic range images showed increased luminance of the images to increase participants' ratings of visual comfort, pleasantness, spaciousness, and satisfaction with the amount of view.

Different studies report colour temperature of lighting to influence the perception of brightness in office spaces. Lighting with a CCT of 5000K and 6000K increases the perception of brightness of the office, compared to 3500K lighting (Akashi & Boyce, 2006; Wei et al., 2014). In the evaluation performed by Manav (2007), for impressions of 'comfort and spaciousness', a 4000K colour temperature was preferred over 2700K. Park et al. (2010) asked in their study participants to evaluate the room impression of a test office under different correlated colour temperature conditions. The conditions of 5000K and 6000K were evaluated by the participants to be alive, concentrative and tensioned, less sleepy, less tedious and less undesirable, while the conditions with a CCT of 3000K and 4000K were evaluated as more comfortable, less tense and less fatiguing. Park et al. furthermore state preferred correlated colour temperature to be dependant of the purpose of the space as well as the specific activities performed. In the user acceptance studies of Dangol et al. (2013), the observers preferred the light environment under LEDs over fluorescent lighting at 4000K. At 6500K no significant differences between the different spectral power distributions of the light sources were measured for the assessed scales. The study showed for the office lighting using LEDs, neutral white light of 4000K to be more preferable than cool white light of 6500K. This may also be influenced by the participants' culture. These results were validated in an actual office environment, with 4000K being preferred over 6500K at a light level of 500 lx (Islam et al., 2015). The observers in the study of Dangol et al. (2013) rated objects to appear more natural under a lighting environment at 4000K than under 6500K, for both LED's and fluorescent lighting. In the study of Boyce and Cuttle (1990) however, the correlated colour temperature of the lamps used ranged from 2700K to 6300K and was reported not to affect the observers' impression of the lighting of the room.

1.2.3. Mood and emotions

Light triggers a wide range of non-visual effects regarding biological functioning and behaviour (Cajochen, 2007). Employees' mood is one of these, and a frequently reported emotional parameter explored for being influenced by lighting. In lighting studies, mood surveys often make use of adjective checklists (Diener & Emmons, 1984; Matthews, Jones, & Chamberlain, 1990; Thayer, 1989). Mood can be influenced by people's emotions, and is in some studies also assessed using emotional state surveys (aan het Rot, Moskowitz, & Young, 2008; Fleischer et al., 2001; Russel & Mehrabian, 1977).

Positive moods at work are identified as key factors in both performance of users as wellbeing (Heerwagen, 1998). Heerwagen reported positive feelings to directly affect brain processes related to performance on tasks requiring creativity and novel problem solving. She reports positively toned moods to be linked to reduced absenteeism, increased organizational commitment, enhanced creativity and problem solving, and more positive social interactions, including increased ability to negotiate in quarrelsome situations.

Bright-light exposure during winter was shown to impact mood by improving self-rated vitality and reducing self-reported depressive symptoms in healthy adults working in an office environment (Partonen & Lönnqvist, 2000). In this evaluation, users were daily exposed for one hour to a light source of 6500K with 2500 lx at eye level, and mood was measured using a seasonal pattern assessment questionnaire. The study of Küller et al. (2006) however, did not find a significant impact of the measured illuminance on mood measured with adjective scales. They did find that countries situated far north of the equator had a significant variation in psychological mood over the year, that did not occur in the countries closer to the equator. Their study showed workers' mood to be at its lowest when lighting was experienced as much too dark and it improved and reached its highest level when lighting was experienced as just right. The mood of the employees declined again when light became too bright. Fleischer and colleagues (2001) reported, illuminance to be a significant influencing parameter of pleasure. Here, pleasure was measured as one dimension of the 'Pleasure-Arousal-Dominance' (PAD) emotional state model of Russel & Mehrabian (1977). The higher the illuminance, the higher the values for the factor 'Pleasure' in their study, and the higher the ratings of how pleasing the experienced lighting situation was. An increase in illuminance and a shift to more direct lighting also lead to higher values for 'Arousal'. Aan het Rot et al. (2008) investigated users' bright light exposure in relation to their mood, in their field evaluation. Bright light exposure was defined as ambient levels higher than 1000 lx during the day, recorded using a wrist-worn device. When more often exposed to bright light, users showed a better mood, and less quarrelsome and more agreeable behaviour compared to low levels of bright light exposure. Comparing exposures from 1000 lx to 200 lx at eye level, Smolders et al. (2012) did not find an effect on mood, measured using a survey. However, their results do suggest that a higher illuminance level can increase physiological arousal, which was based on heart rate measurements.

Viola and colleagues (2008) showed in their field test that compared to white light of 4000K (420 lx on the work surface), blue-enriched white light of 17000K (310 lx on the work surface) improved the positive mood and reduced irritability of subjects. Iskra-Golec et al. (2012) explored the effect of blue-enriched white light on mood, sleepiness and light perception over the work day. They showed mood, by experienced energetic arousal, to be higher in the conditions with blue-enriched white light of 17000K, compared to the warm light condition of 4000K, both with 500 lx measured at the eye level while sitting. In a later conducted study by Smolders and de Kort (2017), mood and the light settings were rated as less positive in a 6000K condition versus a 2700K condition. More positive affect ('happy') and less negative affect ('sad') were measured in the warmer lighting condition of 2700K. It should be noted however, that this later study showed significant differences between the two similar baseline conditions prior to the test conditions.

1.2.4. Sleep and alertness

Besides affecting mood, reduced daytime light exposure has also been shown to affect sleep quality in office workers (Figueiro et al., 2017). Numerous studies can be found using sleep parameters to assess wellbeing, as well as performance of users, of which a cross section will be discussed here. Sleep has a considerable influence on users' ability to think clear, process information and make decisions. With healthy people, alertness or sleepiness can be measured by subjective rating scales. Often in studies on alerting effects of light, standardized fatigue or sleepiness scales are used (Cajochen, 2007). However, the disadvantage of subjective alertness ratings is that control conditions (i.e. placebo's) with lighting are difficult to realize, and intuitive feelings of alertness could influence the user's ratings.

Different studies report decreased daytime sleepiness when exposing participants to high illuminance levels. Consideration of the vertical planes and illuminance ratios is stated by Begemann et al. (1997) to be of great importance, to create optimum luminous environments for circadian rhythm support and direct stimulation. Rüger et al. (2006) evaluated vertical bright light exposure using subjective and objective parameters. They found in their evaluation bright light exposure (5000 lx at eye level) of four hours to reduce sleepiness, but also positively affect subjective alertness, feelings of fatigue and energy. The effect of bright light on psychological variables was found to be time independent in their study since both night-time and day-time bright light reduced participants' sleepiness and fatigue significantly. Bright light exposure at night also increased heart rate and core body temperature of the participants. This effect was not measured at day-time exposure. The evaluation of Smolders et al. (2012) showed participants to feel less sleepy and more energetic after one-hour exposure to 1000 lx at eye level compared to 200 lx (4000K). Their study suggests effects of illuminance on the subjective measures and heart rate to not be dependent on the time of day or duration of the exposure. In the study performed by Borisuit and colleagues (2015), participants were exposed to a daylight and an electric lighting condition during two different afternoon sessions, with 1000-1600 lx at eye level in the daylight and 176 lx in the electric light (4000K) condition. While subjective alertness and physical wellbeing decreased for both lighting conditions in the course of the afternoon, subjects felt sleepy earlier under the electric light than in the daylight condition. In a recent study, Te Kulve et al. (2017) showed a decrease of subjective sleepiness during a bright light session in which participants were in the morning exposed to 1200 lx on eye level, compared to exposure to 5 lx on eye level.

In the field study performed by Figueiro and Rea (2014), a significant increase in employees' light exposure during summer compared to winter was shown, both at work as outside work. The results revealed that during summer the subjects slept significantly more, had significantly greater sleep efficiencies and significantly shorter sleep latencies than in winter. These findings were confirmed in a later evaluation, reporting that high levels of lighting during the entire day to be associated with increased sleep quality, as well as reduced depression (Figueiro et al., 2017). The researchers stated receiving high levels in the morning to be associated with reduced sleep onset latency (especially in winter) and increased sleep quality compared to office workers receiving low levels of lighting in the morning.

The study of Hoffman et al. (2008) demonstrated a potential benefit of variable office lighting (500-1800 lx, 6500K) regarding subjective mood and activation. Variable lighting (500–1800 lx, 6500K), with short peaks in lighting level in the morning and early afternoon, showed modest positive effects on self-reported activity, compared to static lighting (500 lx, 4000K). This effect was not represented by the circadian markers obtained from urine samples. The authors state, melatonin to already have been at its daytime minimum, showing no effect.

In the study of Geerdinck and Schlangen (2006), a lighting system with a high colour temperature was introduced in the office. Even though improvements of the intervention were not reflected in the used health and wellbeing surveys, employees did indicate in the final survey to feel more active, vital and alert when working under the 17000K lighting system (170 lx average at the eyes). In a controlled intervention study within a shift-working call centre, lighting with a colour temperature of 17000K (baseline 2700K) led to substantial within-group improvements of fatigue (26.9%), alertness (28.2%), and daytime sleepiness (31%) (Mills, Tomkins, & Schlangen, 2007). Rautkyla et al. (2010) evaluated lighting of 17000K by exposing students it in their lecture room. After afternoon exposures in the autumn, the students' alertness decrease was reduced. However, these effects were not found in the morning sessions nor in the spring sessions. The authors expected consumption of stimulus like coffee or energy drinks to influence the respondence to the CCT of lighting. The season and the time of exposure during the morning and afternoon are also expected to influence the measured effect. In the study performed by Smolders and De Kort (2017), a one-hour exposure to lighting with a higher CCT (6000K vs. 2700K) showed a higher subjective vitality in the morning. But the metrics arousal and alertness did not show significant effects.

Viola and colleagues (2008) showed in their field test that compared to white light of 4000K (420 lx on the work surface), blue-enriched white light of 17000K (310 lx on the work surface) to improve the subjective measures of alertness and evening fatigue. Daytime sleepiness was reduced, and the quality of subjective nocturnal sleep was improved under blue-enriched white light. In the study of Iskra-Golec et al. (2012) however, no effect of exposure to blue-enriched white light was found on subjective sleepiness, which increased during the day independently of lighting conditions. This is inconsistent with the results of e.g. the study of Lockley et al. (2006), applying objective measures of sleepiness. Through EEG recordings, they showed besides lower subjective sleepiness ratings, a reduced circadian drive of sleep when users were exposed to 460 nm blue lighting, as compared to those exposed to 555 nm more yellow lighting. The circadian drive for sleep affects alertness, performance, and the ability to sustain attention. As pointed out by other researchers, subjective sleepiness ratings are not always matching objective measures of sleepiness (Phipps-Nelson, Redman, Schlangen, & Shantha, 2009).

1.2.5. Cognitive performance, creativity and collaboration

Different studies report effects of lighting on users' performance. Some link these effects to sleep or alertness parameters, as discussed in the previous section, and some report effects on cognitive task performance, creativity, or collaboration.

Already in an early study, Van Ooyen et al. (1987) reported improved task concentration, with increased wall luminance, which created a room rated to be more stimulating. Through linked mechanism analyses, Veitch et al. (2008) suggested paths linking preferred lighting to task performance, through motivation. In a study performed by Linhart and Scartezzini (2011), two energy efficient lighting scenarios, were evaluated for approximately two hours in the evening, using a horizontal illuminance of 232 lx and 352 lx with comparable visual comfort. The performance of the paper-based task was better in the scenario with horizontal illuminance of 352 lx. The two lighting scenarios did not show a significant difference in the measures of computer-based task performance or alertness ratings. Münch and colleagues (2012) found in their study that light exposure of six hours during the afternoon to have an impact on cognitive task performance in the early evening. They showed better cognitive performance in dim light during the early evening after an exposure to daylight in the afternoon of approximately 1000 lx at the subjects' eve level, compared to electrical light exposure of on average 176 lx at eye level (3700K). Better cognitive performance also significantly correlated to lower sleepiness in the evening. In the study of Smolders et al. (2012) morning and afternoon sessions were tested, during which participants were exposed to conditions of 200 lx and 1000 lx at eye level (4000K). The performance effects measured, were most pronounced in the morning sessions and towards the end of the one-hour exposure period. The participants had shorter reaction times and showed increased physiological arousal after exposure to 1000 lx. The study of Gornicka (2008) showed subjective alertness in the morning to be higher in bright light conditions (1150 lx on the eye) than in dim light (70 lx on the eye). Te Kulve et al. (2017) compared bright light exposure of 1200 lx to dim light exposure of 5 lx (both 4000K) and did not find an effect on the performed reaction speed task. Wang and Luo (2017) did report less time needed for an attention task when performed with a 750 lx desk illuminance compared to the conditions with 350 lx and 550 lx. With a 750 lx desk illuminance less time was needed for the task using the 6500K lighting installation compared to the installations with 4000K and 8000K. This study was however performed in a in non-typical office layout with wooden walls. Mills et al. (2007), conducted a study in a call centre where employees work in shifts, evaluating the effect of a high colour temperature on functioning and work performance. Individuals in the intervention group with 17000K lighting showed a significant improvement in self-reported ability to concentrate at the end of the 14 weeks intervention compared to those within the control group where 2900K lighting was used. The intervention group also showed improved work performance (19.4%). Besides the earlier mentioned improvements in alertness, mood, and comfort, Viola and colleagues (2008) showed in their field test that compared to white light of 4000K (420 lx on the work surface), blue-enriched white light of 17000K (310 lx on the work surface) to improve the subjective performance and concentration as well. Without any abnormal sleep–wake schedule being imposed, blue-enriched white light can improve the self-reported measures after daytime exposure to blue-enriched white light in a “real-life” setting for people who work normal office hours. The effects of higher colour temperatures are supported by the findings of Shamsul et al. (2013) that report CCT’s of 4000K and 6500K to be more beneficial for alertness levels and academic activities (e.g. microscopic work and solving complex equations) for both computer-based and paper-based activities, compared to a condition of 3000K. In the study of Wei et al. (2014), comparing luminous conditions of 3500K and 5000K, the self-rated productivity was lower in the higher CCT condition of 5000K with daylight access. In the study performed by Smolders and De Kort (2017), no clear indications were found for beneficial effects on cognitive performance, comparing a one-hour exposure to lighting with a CCT of 6000K with 2700K (500 lx on the desk). This was also the case in the study of Gornicka (2008), in which no evidence was found for an effect of colour temperature of light on alertness and performance during the day. In subjective and physiological alertness measurements, and performance tests, the effect of cool white light (17000K) versus warm white light (2700K) was not significantly different during the exposure for about 9 hours (430 lx vertical).

In the study of Enomoto et al. (2008), dynamic lighting with desk illuminance peaks of 1000 lx in the morning and early afternoon, showed a slight improvement in productivity measured with a simulated office task when compared to static lighting of 750 lx at desk level. Kim and Kim (2007a) report fluctuation of illuminance to not significantly influence reading task performance. This is supported by the results of the field study performed by De Kort and Smolders (2010), in which no significant differences were found in workers’ subjective performance between the conditions with dynamic or static lighting, though measured in an office with extensive daylight contribution during both conditions. In the study of Heydarian et al. (2016), in which 160 participants assessed virtual office spaces, the presence of daylight showed beneficial effects on performance. The participants’ reading speed and comprehension were respectively faster and more accurate in conditions where simulated daylight was available.

Multiple studies report effects of lighting on collaboration. Results are, however, not consistent. Aan het Rot et al. (2008) showed in their study, that when more often exposed to bright light, users show less quarrelsome and more agreeable behaviour, compared to low levels of bright light exposure. In an early study of Gifford, bright light showed to stimulate more general discussion and more intimate communication, while lower light levels over time restricted general and intimate communication (Gifford, 1988). The results of the exploration done by Kombeiz et al. (2017) revealed that self-oriented individuals were more likely to include their negotiation partner in dim warm light than in other lighting conditions, promoting collaborative conflict resolution. This is in line with earlier findings of Baron et al. (1992) that showed participants to judge others more favourable when being exposed to low illuminance levels (150 lx) compared to those exposed to high illuminance levels (1500 lx). In their study, participants exposed to warm white light also reported a stronger preference for resolving interpersonal conflicts through collaboration instead of avoidance compared to participants exposed to cool white light.

Steidle and Werth (2013) report that both priming darkness (imaging a dark situation) and actual dim illumination with 150 lx on the work surface improved creative performance. The authors report that this effect can occur outside of people's awareness.

1.3. Preference and control

Wellbeing can be directly influenced by lighting, as discussed in the previous paragraph, but also via control and matching the individual's lighting preference. Different studies have shown beneficial effects of control on wellbeing (Moore, Carter, & Slater, 2004; Newsham, Aries, Mancini, & Faye, 2008; Sadeghi, Karava, Konstantzos, & Tzempelikos, 2016; van Bommel, 2006; Veitch et al., 2010, 2008). With a wide variation in users' lighting preferences (Galasiu & Veitch, 2006; Newsham, Veitch, Arsenault, & Duval, 2004; Veitch & Newsham, 2000), controls offer a means to adapt lighting to meet the personal preference (Moore, Carter, & Slater, 2000). Ability to adapt environmental conditions to individual preferences is likely to be associated with reduced negative moods and discomforts, and also an increased ability to focus attention on work tasks (Heerwagen, 1998). Newsham and Veitch (2001) showed that the deviation between participants' lighting preferences and the lighting they experienced during the day to be a significant predictor of the participant's mood and satisfaction. Participants experiencing lit environments which are substantially different from their preferred lit environment showed significantly lower ratings of mood, rated lighting quality, and overall environmental satisfaction. Experience of lighting within their own preference range, correlated with increased environmental satisfaction. This evaluation of Newsham and Veitch suggests that no fixed lit environment can match the illuminance preferences of more than around 50% of the office occupants. Provided with individually controllable lighting, Boyce et al. (2006a) showed that conditions indeed were rated as more comfortable by a larger percentage of people than conventional fixed conditions. Results of the evaluation suggested that individual control of lighting tends to maintain motivation and vigilance over the day. Individuals who had lighting control during the workday did not show a decline in vigilance or persistence over the day, whereas those without control did. In the study performed by Veitch et al. (2008), individual control was rated as comfortable by more than 90% of the participants, and showed to beneficially affect users' motivation and wellbeing. Rubinstein and Enscoe (2010) reported workstation-specific lighting to lead to improved users' satisfaction compared to a centralized system. The study of Gene-Harm et al. (2016) showed the use of additional task lighting to improve satisfaction with lighting. They assign the improved lighting satisfaction to be due to the increased perceived controllability of light rather than the actual set illuminance level.

When offered controls, a wide variety of dimming levels is selected by users. In the study by Begemann and colleagues (1997), participants preferred to follow a daylight cycle when exposed to high light intensities. On overcast days, users added roughly around 1000 lx artificial lighting. On clear days, with daylight levels up to 2000 lx, the added artificial lighting level decreased from 1200 to 500 lx with increasing daylight. In their study, situations with and without the use of blinds were evaluated. When daylight levels were above 2000 lx, the added artificial light increased in the situation without blinds but decreased in the situation with blinds. The authors stated that balancing the spatial brightness ratio in relation to weather type to be far more important, than following horizontal working plane illuminance levels. In a field evaluation with French office workers, the opposite effect was observed. Many occupants chose lower artificial light levels when daylight was bright, in order to benefit more from daylight (Escuyer & Fontoynont, 2001). Newsham et al. (2008) found a negative correlation between prevailing light levels and dimmer choices of users as well. Occupants did not use personal control to maintain a constant desktop illuminance, even though desktop illuminance appeared to be a better predictor of the selected levels than many luminance-based predictors. In the study of Escuyer and Fontoynont, the preferred colour temperature of the artificial lighting added to the available daylight in the office did not correlate with daylight colour temperature. At low daylight levels of 500 lx the average preferred colour temperature was for most users around 3300K which increased to 4300K at levels above 1500 lx. Inconsistency in these results could be caused by differences in daylight conditions, or by a difference in users' consciousness of using the controls. In some studies, the users were asked to use the controls to set their visual optimal condition, while in others the normal daily use was analysed, where personal importance of energy saving by optimizing daylight usage might be incorporated in the users' considerations. In the study of Begemann et al., the participants were asked to maintain their normal daily work routine in the lab office space. They could adjust the artificial lighting components according to their preference and overall feeling of wellbeing as a function of the prevailing and changing daylight conditions. In the study of Escuyer and Fontoynont, results were based on measurements and interviews in an actual office.

Escuyer and Fontoynont (2001) found that people who spend more than 70% of their time working on the computer select lower light levels (100-300 lx), while people who spend less of their time on a computer select higher light levels (300-600 lx). This is in line with results of Berrutto et al. (1997). Logadottir and colleagues (2011a) show that the preferred illuminance is influenced by variables inherent in the experimental design within which it is measured, including the available illuminance range and the anchor, being the initial setting before adjustment. As the maximum available illuminance in a range increased, the preferred illuminance also increased, with a centring bias. Higher anchors lead to higher settings of preferred illuminance. This effect is confirmed by de Korte et al. (2015), who found in their evaluation higher pre-set values to result in an higher adjusted illuminance on desk. After adjustment by users, the visual comfort was higher, but that was independent of the pre-set values. An effect of personal control on task performance measured by a dual visual memory task was not found by the authors. The study of Heydarian et al. (2017), using immersive virtual environments to evaluate end-user lighting-related behaviour, observed extroverts to be significantly more likely to prefer maximum achievable lighting compared to other people.

Based on the evaluation of 14 UK office buildings, Moore and colleagues (2000) stated that the perception of not having control and the dissatisfaction this often causes to be linked to negative perception of lighting quality in the office. Escuyer and Fontoynont (2001) showed that occupants preferred to be able to override an automatic system, even though the daylight linked automatic system was valued by the users. The study also showed the complexity of the control device to limits occupants to utilize the user interface. This is supported by the findings of Sadeghi et al. (2016), who observed a higher frequency of lighting control actions when offering an easier interface. They showed the comfort ratings to significantly improve when occupants could override the automated system. Participants in the study of Escuyer and Fontoynont (2001) stated that the ideal lighting control system would consist of combined automatic and manual control. In a survey study run with occupants of a refurbished UK office, occupant intervention by localized switching was positively supported by the office users (Barlow & Fiala, 2007). The use of automatic lighting controls was not favoured by the occupants surveyed, with 59% of the users voting against turning lights off automatically. The value of the presence of controls was affirmed by Baričič and Salaj (2014). From survey data of 1036 office employees, they concluded that besides the regulation of the air-conditioning, the cleanliness and the orientation of the workspace, the lighting of the workspace and the regulation of lighting had a significant impact on the satisfaction of employees with the workspace. A manual switch combined with an absence detector was greatly appreciated by the participants in the study of Gentile et al. (2016), resulting in high energy savings. The study did report that participants perceived the automatic controls as stressful. Correct implementation of controls remains key to achieving satisfactory conditions.

1.4. Open office challenges

Many of the studies referenced in the previous Section, have been done in office environments with a one-to-one relationship between user and control device. In the open plan office, this one-to-one relationship, tends to vanish, being the window, the blind, or the light switch. This makes effective individual control much more difficult. Bordass et al. (1993) already showed in their study, perceived control to decreases with an increase in number of users in the office.

In open plan offices, control over the general lighting system is more challenging on an individual basis, which often results in configuring control groups. Moore and colleagues (2002a) showed with their analyses the use of controls to be linked to the size of the group of users sharing the controls. Larger control groups were associated with less user control actions.

Offering control to achieve individually preferred lighting, also introduces the risk of disagreement between users due to different preferred light settings. If preferences of different people that share a system do not align, conflict can come to exist. In line with the definition of Putnam and Poole used by (Niemantsverdriet, 2018), conflict is defined in this thesis as “the interaction of interdependent people who perceive opposition of goals, aims, and values, and who see the other party as potentially interfering with the realization of these goals” (Easterbrook, Beck, Goodlet, Plowman, & Sharples, 1993). The size of the control group was shown by Moore et al. (2000) to correlate with the experience of conflict, with higher conflict measured for larger control groups. Larger control groups may not necessarily cause conflict. Appropriate design of the control zones and the luminaire group layout is important, as well as providing the users with information to increase their awareness of the social context.

When a higher frequency and degree of conflict is experienced, Moore and colleagues (2000) found that users are more likely to avoid using controls. This however does depend on the personality of the users. In the latter study, avoidance to use controls showed a strong negative correlation with the degree of control occupants perceived they had. The perception of having control is considered as important as the actual exercise of control. Besides the perspective of the user using or intending to use the control device, the open office also introduces co-workers experiencing control actions made by others in a different control group. The visual field of multiple users needs to be considered when dynamics by control are introduced in an office. As stated by Leaman and Bordass (1993), negative opinions regarding control are likely to have a negative effect on occupants' assessments of their environment.

1.5. Hypotheses

In previous Sections of this Chapter, the importance of wellbeing in the office environment has been substantiated. Artificial lighting is needed in offices to meet recommended levels for visual performance, but it could also play a role in further improving users' health, happiness or comfort. In previous Sections, benefits of lighting are introduced, affecting wellbeing in general, as well as the interlinked components of wellbeing as users' appreciation of the environment, mood and emotions, sleep and alertness, and performance. To make use of these potential benefits of the right lighting, lighting systems need to be designed and implemented with proper care of the application.

The multi-user character of the, nowadays widely applied, open plan office, introduces challenges compared to the traditional more enclosed office. The work presented in this thesis explores how to improve wellbeing by offering satisfying lighting environments for the individual in these multi user office spaces.

This thesis will address the following main hypothesis:

- By offering personal control of shared lighting to users, the satisfaction of the individual office worker can be improved.

To explore this main hypothesis, a first field study was designed. Based on the insights gained in this first study, topics for further exploration emerged. These have led to the following sub hypothesis:

- Based on control behaviour with the lighting system, users can be profiled, to enable offering lighting conditions satisfying their preference to secure users' comfort with the lit environment.
- The wall luminance in the visual field of the user will influence the user's preferred task lighting.
- A distinction can be made between noticeability and acceptance of light changes, in which the co-workers' acceptance of dimming increases with an increasing fading time, and by feedback regarding the reason of dimming.

1.6. Structure of the thesis

In Chapter 2, the main hypothesis is tested through a longitudinal study in an open office environment, in which personal control of the general lighting system is evaluated. In this office space lighting is shared between users, due to the standard lighting grid. Control is offered using the smallest control zones possible while still offering equal sense of control to all users. Through personal control interfaces users could control a shared group of luminaires, resulting in consensus control.

A series of field and lab studies is performed, to further explore a few selected topics and establish recommendations for individually satisfying lighting in multi user spaces. Dissatisfaction could occur due to conflicting lighting preferences of users. Chapter 3 presents the exploration of user personalities and their lighting control behaviour. Users from two field evaluations are profiled based on their interactions with the lighting system in order to predict the risk of conflict occurring. Knowing the user profiles allows to take measures to avoid conflict, as informing other users or considering users when automatic adjustments are made. Chapter 4 presents the lab study in which the influence of the brightness of the walls enclosing the open office is explored. The uniformity and luminance levels of the wall are evaluated for their effect on selected desk illuminance levels within and between individuals. Conflict can also occur when co-workers are disturbed by experiencing light changes triggered by others. In Chapter 5 the exploration of granular dimming of lighting is presented. In a laboratory study the dimming speed by which light changes are made is evaluated for its effect on the noticeability and acceptance of a light changes. The thesis will end with a discussion section and an outline of the main conclusions.

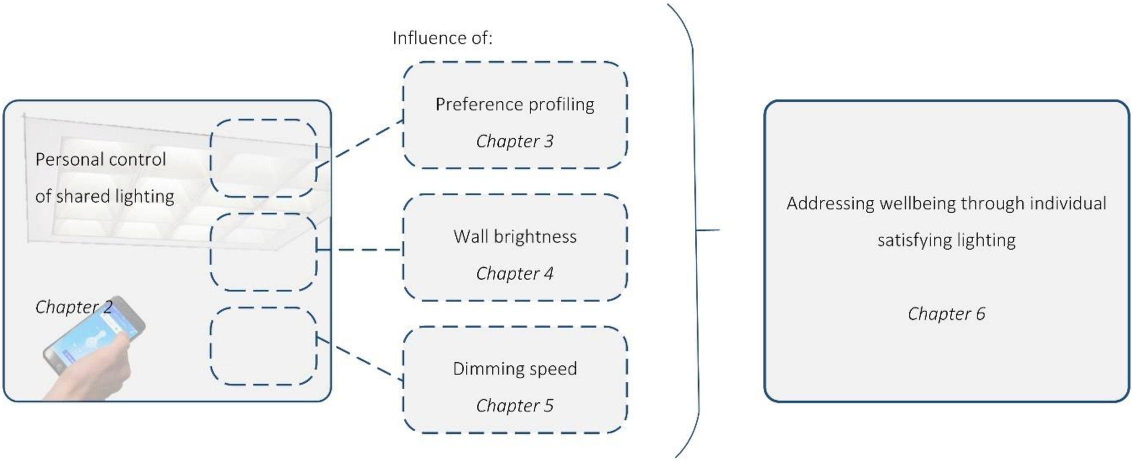


Figure 3. Structure of the thesis.

Chapter 2

2. Consensus light control in open office environments

This chapter is based on the following publication:

S. Chraibi, T. Lashina, P. Shrubsole, M. Aries, E.J. van Loenen, A.L.P. Rosemann, Satisfying light conditions: A field study on perception of consensus light in Dutch open office environments, Build. Environ. 105 (2016) 116-127.

Workplace innovation has been changing the European office landscape into mostly open spaces, where enhanced interaction between people is combined with efficient use of square meters. However, challenges are found in offering individually preferred environmental conditions in these multi-user spaces, especially when dealing with shared systems like the general lighting installation.

Previous studies clearly show the benefits of offering personal control as a means to achieve individually preferred lighting. Most of these benefits were demonstrated in private offices or situations where users have a clear "personal" light source.

Lighting systems in open offices are often designed as a regular grid of luminaires to deliver uniform lighting in the space. This results in a ceiling grid of luminaires that does not match the desk arrangement in most cases. Users in the open office do not have a personal luminaire, which makes it challenging to offer personal lighting control. By combining luminaires in control groups, users could be offered consensus control. The question is whether consensus control would bring advantages or disadvantages.

This Chapter presents the results of a field study evaluating consensus light control in an open office. In a within-subject comparative experiment with repeated measures, 14 users experienced a reference no-control condition and a condition in which they were offered control over a zone of luminaires. Data was collected by objective measurements as well as subjective surveys and interviews.

In this study, it is shown that consensus control in an open office improves satisfaction of individual users with the quantity and quality of light. Even though the controllable light is shared, consensus among users results in an improved lighting environment for the majority of the users. Selected illuminances in the condition with light controls were on average lower than in the reference condition, resulting in lower energy usage by lighting.

2.1. Introduction

European workplace design has experienced a transformation over the last decades with the majority of today's modern offices being open office spaces. Despite the often-expressed concerns of lower worker productivity and satisfaction, the trend does not seem to slow down. Therefore, in today's offices, it becomes even more relevant to create office environments that meet individual needs.

2.1.1. Benefits of personal lighting control

Standards provide lighting recommendations for different visual tasks to ensure a comfortably lit environment. However, different studies have already shown satisfying light conditions to differ significantly between individuals. Preferred desktop illuminances for office tasks range from 80 lx (Veitch & Newsham, 2000b) to around 1500 lx (Newsham et al., 2004a) between individuals. With a fixed light level installation, Boyce and colleagues (2006b) demonstrated that the maximum number of occupants that would be within 100 lx of their preferred illuminance is only around 65%.

Why would we want to offer lighting that serves the preferences of individuals? An exploration in a laboratory study with a cubicle office setup in 2001 showed that by offering illuminances close to people's own preferences, a significant improvement in ratings of mood, lighting satisfaction, and environmental satisfaction can be established (Newsham & Veitch, 2001). In 2004, Newsham and colleagues conducted an experiment in a mock-up office where they placed participants in a cubicle office setup under a lighting configuration for a single day, without any control over the lighting until the second half of the afternoon when all participants were offered a means to control the lighting. The results showed improved ratings when introducing individual control over lighting, but also that these are not simply due to the availability of control. Exercising control to achieve preferred conditions improved mood, satisfaction, and comfort. Participants that made the biggest changes to the lighting conditions after they were given control tended to register the largest improvements in subjective measures (Newsham et al., 2004a).

Benefits of lighting control were also shown in field studies. Veitch et al. (2008) demonstrated in an office setup with cubicles, that people who perceive their office lighting as being of higher quality, rate the space as more attractive, report a more pleasant mood, greater well-being at the end of the day, and improved motivation and vigilance. In 2010, Veitch and colleagues conducted a field study on four floors of an office building with cubicles in Canada, in which they showed the availability of individually-controllable lighting to result in more favourable office appraisals and higher levels of environmental satisfaction, with an indirect link to higher job satisfaction (Veitch et al., 2010). Moore et al. (2004) performed an evaluation in existing office buildings with and without controls and found that the presence of lighting controls seems to lead to a higher degree of satisfaction with planar illuminance. In another analysis of an office building with user control, Moore and colleagues (2002b) showed an increased importance of lighting control as levels of discomfort were raised. However, the study also showed that around one-third of the occupants to report a negative perception of controls, suggesting a partial failure of current lighting control systems.

In a study performed in four identical private offices, Sadeghi and colleagues (2016) showed a higher comfort rating from the users that evaluated the offices with control (wall switch or web application). A higher frequency of lighting control actions was observed when offering the more easy-to-access web interface. However, it did not affect the comfort experienced by the users. A study performed by Aghemo and colleagues (2014) showed a lower rating of the lighting conditions in the office when control was extended from on/off to regulation of the luminous flux. Participants did, however, indicate that their control actions in the extended situation mainly occurred when the automatic system was not working properly, which was absent in the manual on/off situation.

Benefits are not only limited to the contentment of users. When given control, office users on average select a lower light level than the recommended 500 lx desk illuminance resulting in energy savings (Boyce, Eklund, & Simpson, 2000; Boyce et al., 2006b). A review of 88 publications by Williams et al. (2012) reported the average lighting energy saving potential by personal control to be 31%. A field study by Galasiu and colleagues (2007) reported energy savings by personal control over downlights to be 11%, increasing up to 42% when combined with other control strategies like daylight harvesting and occupancy control.

2.1.2. Consensus control in the open office

Many benefits of personal control have been demonstrated in studies with private offices, cubicles or situations where users have a clear “personal” light source providing lighting in their workspace. These studies are often performed with luminaires positioned directly above the office worker and with the ability to be individually controlled. With trends like Gensler’s activity-based workspaces, the open office concept is becoming commonplace in the office landscape (Gensler, 2008). Lighting systems in (open) office spaces are often designed as a regular grid of luminaires to satisfy the local regulations, building codes, and design guidelines for lighting with respect to illuminance levels and uniformity in the most efficient way. The number of required luminaires is calculated (based on regulatory and cost constraints) and can be visualized as a regular grid of luminaires providing uniform general lighting in the office space. The furniture layout in the same office is often not known or not being considered during the lighting design process. It is also likely to change throughout the lifespan of the lighting installation. As a result, the ceiling grid of luminaires does not match the desk arrangement in most cases. Even though the lit environment is designed to meet user needs, the lighting grid is often designed using the space dimensions as the primary input and not the users.

A space-based organisation of luminaires makes it challenging to offer lighting controls for open offices in a truly personal way. After an exploration in 14 existing office buildings, Moore et al. (2000) already discovered that problems with user-controlled lighting will arise after an attempt to introduce personal control into open-plan environments. For some users, it will be obvious which luminaire is linked to their workplace, others could have workplaces positioned in between luminaires or may even have the feeling of controlling “someone else’s light”. By combining luminaires in control groups, such that all luminaires in one group act as one, users could be offered consensus control. Multiple users get dimming control over the same group of luminaires in their proximity which delivers light to a cluster of desks. Based on the analyses of the existing installations, Moore and colleagues (2000) suggest reducing the likelihood of conflict through the use of small control groups and locally situated control. With a minimum number of luminaires per control group the benefits of consensus control can be maximized, while equally empowering users.

2.1.3. Problem statement

When sharing the control over office lighting, difficulties might arise when trying to reach a consensus over the preferred light level, due to the variety of individual light level preferences. This collective way of consensus control might, therefore, lead to conflicting light preferences between users. The benefits office users could experience from lighting within their individual preferences would then be defeated by the potential dissatisfaction when needing to reach consensus with people having different profiles regarding lighting preference or behavioural patterns. It is expected that consensus in workplace lighting levels will improve the appreciation and light perception of office users in an open office environment compared to a situation without controls. The study described in this Chapter evaluates the added value of personal control in an open office context.

2.1.4. Research hypothesis

In this research, it is hypothesized that office users experience a higher satisfaction with lighting in the office when they are offered a means to control the group of luminaires affecting their workplace compared to a situation offering no control over lighting to the users while the system delivers a fixed uniform light level to the entire office space.

This research will address occupant evaluations in a reference condition without lighting control compared to an experimental condition with lighting control assessed in a field study. The methodology used, the results, and a reflection on the results will be discussed in this Chapter.

2.2. Methodology

In general, people are recognized as being unreliable sensors for light comfort, where discomfort is often easier to evaluate (Boyce, 2003). The perception of discomfort is often related to pain and negative extremes while the perception of comfort is related to feelings of wellbeing, luxury, and plushness, and changes little over time. Evaluation becomes challenging when it does not concern extreme shifts, but small positive changes of satisfaction over a situation where users have experienced acceptable lighting in offices without control. To deal with this anticipated positive shift from neutral or satisfied correctly, a longitudinal field study has been designed.

2.2.1. Testbed

The experimental testbed used for the field study was developed in an office space on the 4th floor with a south facing façade in Eindhoven, the Netherlands. Figure 4 shows the top view of the testbed facility and Table 1 an overview of material characteristics. The lighting system consisted of conventional fluorescent lamps (Philips TL5 49W) operated with DALI high-frequency dimmable ballasts with a linear dimming curve. The dimming curve is derived by measuring the illuminance at a target spot for various relative light output levels of the luminaire. The relative light output of the luminaire will be further referred to as the dimming level.

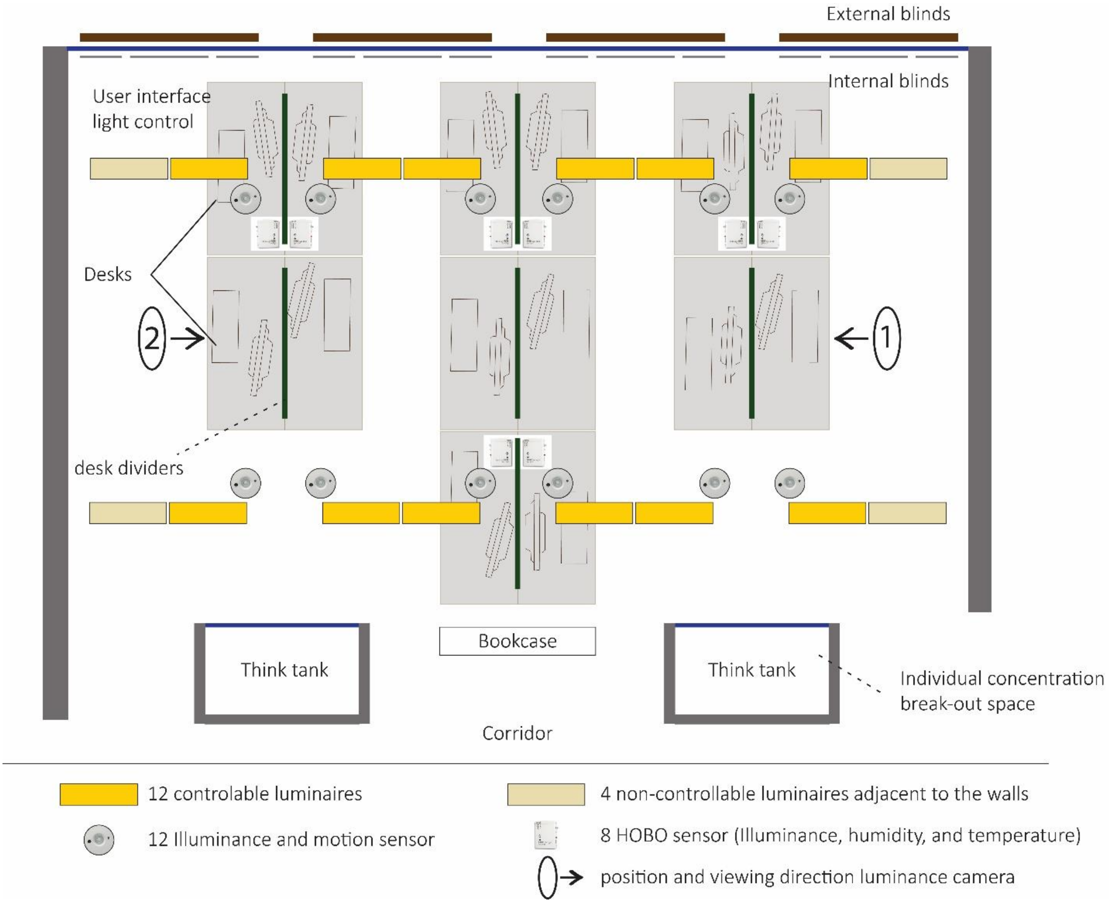


Figure 4. Top view of the testbed area, with controllable luminaires and non-controllable luminaires adjacent to the walls, the position of the HOBO sensors, the illuminance and motion sensors, and the position of the luminance camera.

The twelve inner luminaires were controllable by the users with a personal user interface, while the four luminaires adjacent to the walls were controllable by the researchers and fixed at a default level to maintain sufficient and uniform wall illuminance and not influence overall space appraisal negatively (Wright, Hill, Cook, & Bright, 1999). Using recommendations from literature, the controllable luminaires were combined in a minimum control group size (Moore et al., 2002a) of two luminaires each, as shown in Figure 5, to provide equal sense of control (Moore et al., 2004) to the maximum of three users in every control group. Had the luminaires not been grouped, the middle person would be disadvantaged compared to his neighbours, who have luminaires above their desk. Luminaires in one control group were commissioned to behave identically. The testbed was equipped with 12 illuminance and motion sensors. Daylight harvesting (adjusting electric lighting based on the available daylight in the space) was not used during the entire length of the study to remove the potential noise of artificial light changes in response to daylight. The occupancy-triggered light control in the testbed was controlled for the whole space, turning all lights off when the space was unoccupied and switching the lights on at the last selected level when the first person re-entered the space. The participants had their desk equipped with one or two PC monitors for their office tasks. The luminance of the PC monitors with a blank white screen display ranged from 100 to 150 cd/m^2, measured in the reference condition (average illuminance of 500 lx on the desk surface, excluding the daylight contribution).

Table 1. Surface properties.

Surface	Material	Colour	Luminous reflectance
Walls	Painted Stucco	White	0.83
Ceiling	Mineral wool tiles	White	0.79
Floor	Carpet	Grey	0.08
Green desk divider	Fabric	Green	0.59

For daylight and direct sunlight management, the testbed provided motorized internal as well as external blinds. The external blinds could be set to manual or automatic control mode using the wall mounted interface underneath the windowsill. Internal blinds could only be controlled manually using a remote control, placed on the windowsill. The internal as well as the external blinds were divided into four controllable segments each. The interfaces for the segments were for general use, but more accessible for the users adjacent to the window. The control means for the blinds did not change during the test.

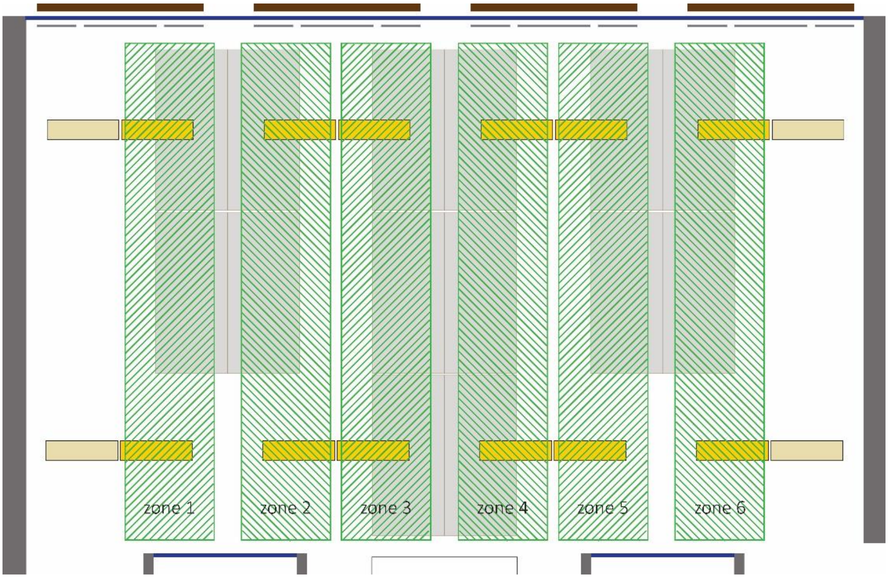


Figure 5. Top view of the testbed with in total 6 control zones, 2 luminaires in each zone.

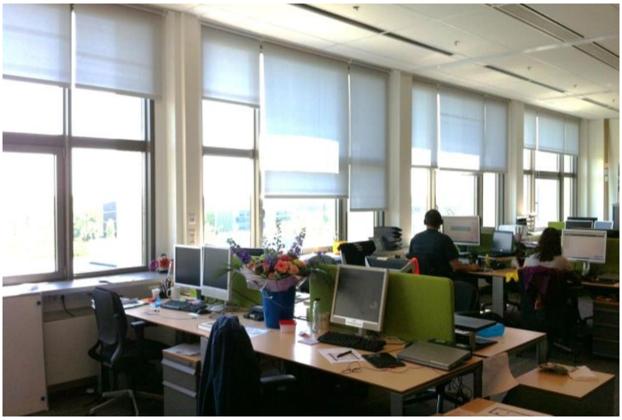


Figure 6. Testbed – interior impression, with desk dividers between desks.

2.2.2. Study design

The study was designed to have a reference period as well as a user-control period. The study started with a reference no-control condition where all luminaires were set at 100% output delivering an average illuminance of 500 lx on the desk surface, excluding the daylight contribution. This condition was followed by a user-control condition with a default dimming level of 60%, representing an illuminance of 300 lx. The 12 controllable luminaires were adjustable in a range from 1-100% luminaire output, the four non-controllable luminaires adjacent to the walls were fixed at the default dimming level of 60%. At the end of the study period, the no-control condition was repeated by removing the controls and setting all luminaires back at a dimming level of 100%.

The study was designed as a repeated measures within-subject comparative experiment. To closely mimic office conditions and tasks, it was decided to run the experiment as a field study (as opposed to lab conditions). A longitudinal field study was designed to deal with the anticipated small positive shift in user satisfaction, and the influence users' daily office tasks could have on the evaluations. The longitudinal design also allowed for participants to unconsciously discover their individual lighting preferences as well as their preference as part of a group. To minimize the effect of the highly dynamic changes of the outside conditions, the duration of the experiment covered periods related to different climate conditions. The study started after the holiday period, due to the availability of the participants, and ranged from September to December. Counterbalancing the experimental conditions minimized the effect of the changing outdoor conditions, as well as the influence of introducing and removing the controls from the users. At least six weeks of data per experimental condition and participant was captured, excluding the first week of control. Figure 7 visualizes the periods of the study on a timeline. The periods followed one another directly.

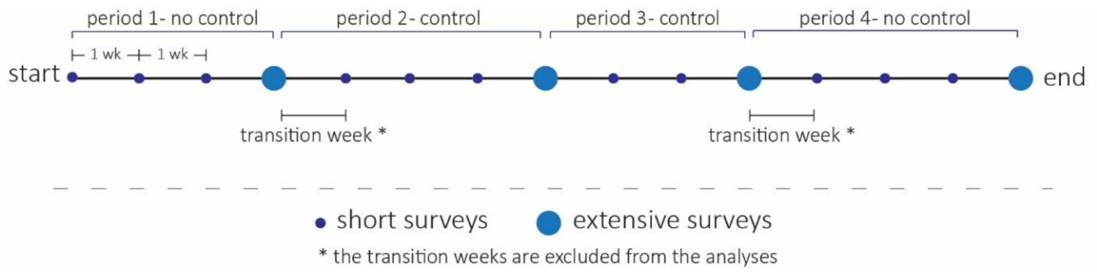


Figure 7. Design and timeline of the study.

During the user-control period, participants were offered personal control by means of a personal smart device placed on their desk as well as a directly accessible widget installed on their PC. Each controller was assigned an identifier that was permanently linked to a particular control group of luminaires. During the user-control period, lighting could be controlled by the users at any point in time by setting the slider to the desired light level (Figure 8). After changing the slider position, the output of the luminaire group was adjusted with a fading time (time to reach the final state) of 2 s. The controller included sufficient steps to offer a perceived continuous slider. The luminaires of the control group stayed at the set dimming level until the next control action within the control group was performed. The dimming level could be overwritten by every user in the zone, at any point in time. After a change was made, the user interface of the users in the zone was updated to present the current dimming level of the luminaire group.

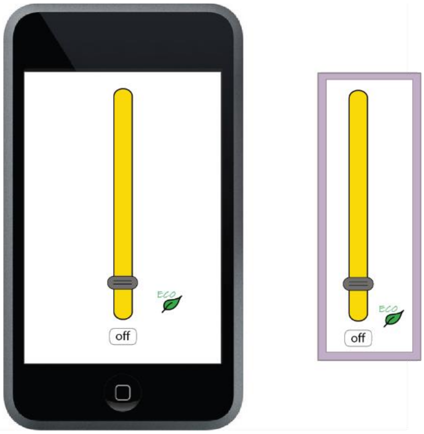


Figure 8. User interface for light control, iPod application (left) and PC widget (right).

Walls enclosing the testbed were in the reference condition as well as in the user-control condition illuminated with fixed dimming levels of the wall adjacent luminaires, resulting in an average vertical illuminance of 145 lx on the walls, and an average luminance of 43 cd/m^2 ranging from a minimum of 23 cd/m^2 to a maximum of 96 cd/m^2, measured in the absence of daylight, with general lighting set to generate an average illuminance of 500 lx on the desks.

Figure 9 shows the luminance distribution of both walls enclosing the office space. Two reference desks at both ends of the space are selected, facing respectively the east and west wall, to describe the luminance scene of the testbed. Measurements were taken from the indicated viewing position of the participants (shown in Figure 4). For the measurements of the horizontal task luminance, a white paper was placed on the desk surface while measuring the average luminance of the entire desk. For the PC screen-based task luminance measurement, a white screen page was used. The task luminance was measured with the adjacent computer monitors turned off. The luminance ratios experienced by the participants are presented in Table 2 using the average values.

Table 2. Experienced luminance ratios in the reference condition.

Luminance ratios	East wall	West wall
Average wall : direct surrounding (desk divider) : horizontal task	1 : 0.48 : 2.90	1 : 0.35 : 2.52
Average wall : direct surrounding (desk divider) : PC screen	1 : 0.48 : 3.80	1 : 0.35 : 3:35

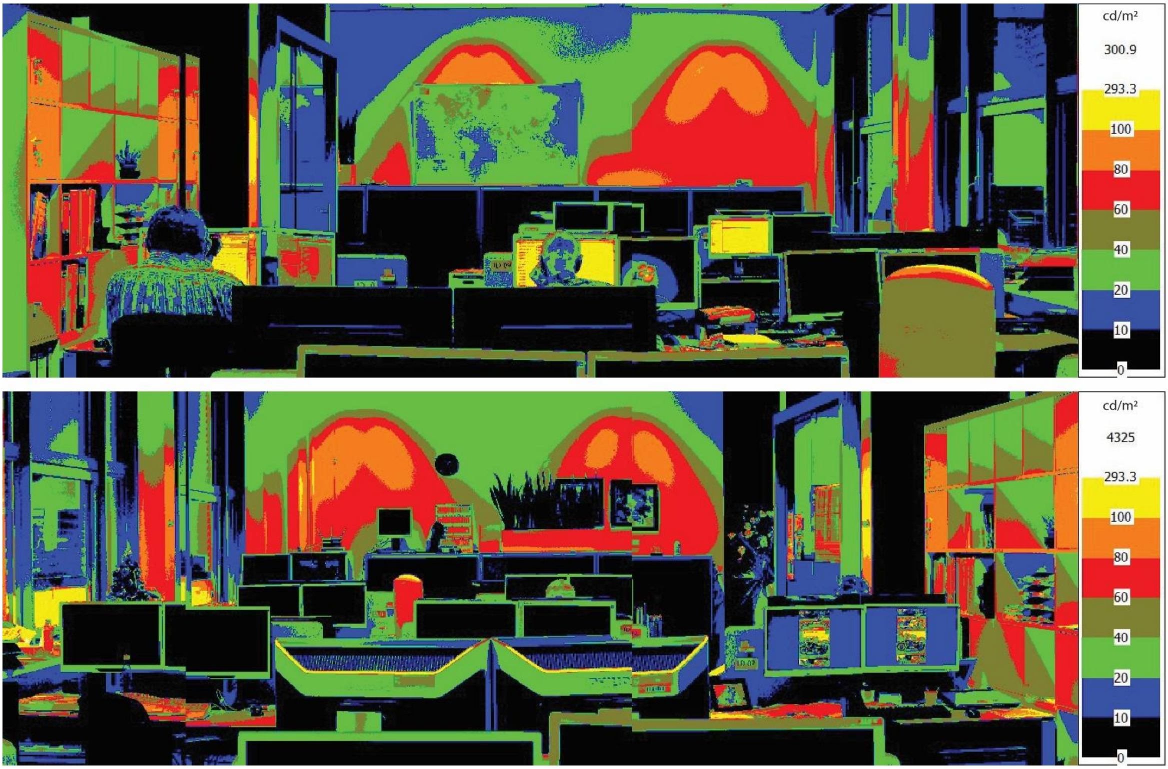


Figure 9. Luminance distributions of the office space in reference condition – east (top) and west wall (bottom).

2.2.3. Participants

For the study it was targeted to recruit a group able to participate entirely as a group in the test, and already used to working in an open office environment. This would exclude other factors as new neighbouring colleagues, and a new office type. It was also targeted to find a group already used to working on the south façade, meaning having experience with direct sunlight and the usage of blinds. Other inclusion criteria encompassed no experience in setting up user experience studies or not being biased regarding lighting designs. The population also needed to be representative for average office employees. Recruitment was done with support of facility management. Group managers were consulted, and after their approval their groups were approached for their willingness to participate.

After the recruitment phase, a group of 14 administrative workers were invited to participate in the study and were relocated to the testbed for the study duration. The participants did not work on research topics themselves and were naïve regarding lighting or perception knowledge.

The participants were offered fixed workplaces similar to their normal office setup, which was located on the same floor of the building facing the same façade. The position of occupants in relation to the windows as well as to their colleagues was kept identical to the greatest extent. The participants (30 – 65 years, 3 females and 11 males) worked on their actual job tasks while experiencing the study conditions. The participants were at the same corporate hierarchical level. Participants did not have fixed working times. Most participants started their workday between 8 and 9 AM and ended their workday between 5 and 6 PM. All participants were Dutch-speaking (as a first or second language) and had good English reading and speaking skills. Prior to the study, the participants were only acquainted with the control possibilities for the external blinds.

The study design and objective were not shared with the participants beforehand. The participants were informed to be part of an evaluation regarding a general open office environment concept and would receive study details afterwards, to enhance the study quality. At the start of the user-control condition, the users were informed about the lighting control option that they received. The participants received a small participation fee at the end of the study, of which they were not informed beforehand.

2.2.4. Objective measurements

The objective measures consisted of data logging as well as sensor input. During the study, log files were created of the luminaire dimming levels (1-minute logging), the energy usage by Plugwise modules (FW 2.36+) wired into each luminaire (1-hour logging), the use of the light controls (instantaneous logging), and the use of internal and external blinds (4-minute logging). Sensor input consisted of readings of the 12 ceiling-mounted light sensors (Philips PLOS-CM-KNX) (1-minute logging) and eight desk-mounted HOBO sensors (Onset U12-012) measuring the relative desk illuminance, the relative humidity, and the temperature (5-minute logging). Due to the sensitivity of the HOBO photosensor to incident lighting from different directions (spatial sensitivity), calibration to absolute illuminance was found to be inaccurate. Therefore, the illuminance distributions were analysed relative to each other. The exterior illuminance is obtained from an external weather station (Wago KNX/EIB/TP1 Module 753-646) installed on the roof of the building.

2.2.5. Subjective measurements

The subjective evaluations were collected via online surveys, interviews, and a paper diary booklet placed at their desk that each participant could write in at any point in time during the full length of the study. The diary consisted of an A5 booklet in which participants could make notes of their absence or things they noticed in the office space related to environmental aspects such as electric lighting, daylight, temperature, noise level, air ventilation, or other incidents they wanted to share or capture. Survey questions and the diary headings were presented in English with a Dutch translation underneath each item. At the end of every week, the participants were asked to fill in an online survey. Two types of surveys were used: a short and an extended survey (Figure 4). The short survey had the same items recurring every week for the full length of the study. The short surveys included scales evaluating the perceived lighting quantity, quality, and glare. The participants were asked to evaluate the light quantity on their desk and PC monitor, from the artificial lighting as well as from daylight on a 7-point scale, ranging from 'too little' to 'too much' (Moore et al., 2004). Besides using the scale to analyse whether lighting was experienced as brighter or darker than they preferred, the assessment of light quantity was recoded into four rather than seven steps, allowing for an overall assessment of dissatisfaction with the quantity of light. Figure 10 illustrates the original scale as well as the clustering on the recoded scale.

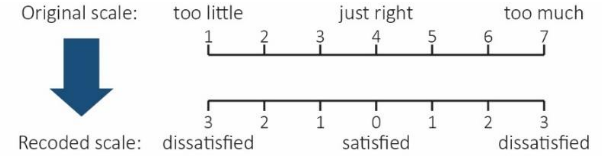


Figure 10. Original and recoded scale light quantity assessment.

The components labelled 'lighting quality' (seven items) and 'glare' (two items) (Veitch & Newsham, 2000a) were created by taking the average of the responses of the contributing items with scores ranging from 1 to 7 with higher values indicating better quality or comfort, respectively. Results from the weekly surveys were aggregated in one average value for each participant per condition.

At the end of each of the four study periods, the survey was extended with additional items. Satisfaction with the environmental conditions was evaluated using comfort scales of Osterhaus (2005) and Veitch et al. (2002) for temperature, acoustics, and air quality in the office. The mood of the participants was evaluated regarding dominance, arousal and pleasure in all conditions using the 3-factor Mood scale of Russel and Mehrabian (1977). The perceived level of control and the level and degree of conflict experienced due to the use of the lighting controls were evaluated in the user-control condition (Moore et al., 2000). Conflict is explained as situations in which people have different preferred outcomes that are potentially interfering with each other.

After each extensive survey, an interview between participant and researcher was conducted to further elaborate on what was captured in the surveys or the diary, as part of a triangulation approach. Interviews delivered complementary qualitative information used to understand the data and the results obtained.

The first week of control is excluded from the analyses due to a deviation in the behaviour with the controls compared to the rest of the user-control condition. This study focussed on the user experience when having the ability to select preferred lighting and not in evaluating the user novelty experience with controls.

2.2.6. Analyses

Most of the elements included in the surveys were evaluated by the participants on an ordinal scale. Due to the ordinal data and the relatively small sample size, the data was analysed using a non-parametric Wilcoxon signed ranks test (2-tailed). For the significance tests, a liberal level of significance of p=0.1 was motivated by the explorative nature of this study, a relatively small sample size, and the use of non-parametric statistics. Effect size calculations are done using Pearson *r*, calculated using $r=Z/\sqrt{N}$ of Rosenthal (1994) (from: Field, 2009). Interpretation of the values is done following guidelines of Cohen (1988), with 0.1=small effect, 0.3=moderate effect, and 0.5=large effect. Correlations are analysed using Kendall's tau non-parametric correlation test. For the analyses, IBM SPSS Statistics is used.

Notes of interviews were systematically digitally logged after each interview, structured based on the general topics such as blinds, artificial lighting, and controls. Data of the interviews was analysed by marking key phrases in the data set, after which concepts were identified which could be named and clustered in categories, an approach very similar to the Grounded Theory methodology. Data of the interviews is used to complement the quantitative and objective data.

2.3. Results

The obtained results will be presented with a distinction between objective and subjective results. Different variables are analysed for their impact on light preference or satisfaction of the participants in this study. No effect is found for age, gender, the position of the user in the office space, as well as the position of the user related to a luminaire.

2.3.1. Objective results

The study included two times three weeks without control, with luminaires set to a dimming level of 100% luminaire output corresponding to an average desk illuminance of 500 lx by artificial light. In the six weeks with user-control preferred dimming levels were set by the users within the range 1 to 100%. Figure 11 shows the distribution of luminaire dimming levels during the user-control period of all six control zones, as shown in Figure 5. Each zone consists of two luminaires, with the same distance from the window. During the control period, the luminaires in the office area were 41% of the time on maximum output, and 56% of the time below a dimming level of 60%. Figure 11 illustrates that during the user-control period there were zones that were mostly "dimmed" (zone 2 and 5), mostly "bright" (zone 1, 3, and 6), and a zone that has been labelled "medium dimmed" (zone 4).

Despite the non-uniformity of lighting over the zones, none of the participants stated to have experienced light level differences between the zones to be disturbing. Often dimming level differences were only observed when looking at adjacent luminaires; not when looking straight forward in the office space.

The frequency in which the controls were used differed during the study. In the first week that the participants were provided with controls, three changes per user per day were made by 12 different users on average. This week is excluded from the analyses due to its variant character. In the remaining six control weeks, actions were performed by changing individuals with three changes a week by on average three users. Similar to previous studies, the users in this study showed different usage behaviours ranging from active users to users with limited performed control actions (Meerbeek, Gritti, Aarts, van Loenen, & Aarts, 2014). Figure 12 presents the proportion of control actions performed throughout the day. The majority of control actions took place at the start of the work day (45%) of which two-third was to dim down. The other half of the control actions took place throughout the rest of the day (Figure 12), with a small increase again at the end of the day when exterior lighting conditions start dropping, of which little more than half was to dim up. The sunrise in the control period varied from 7:23 till 8:19 am, and the sunset from 4:34 till 6:31 pm. Average exterior illuminance levels are provided as a reference in Figure 12.

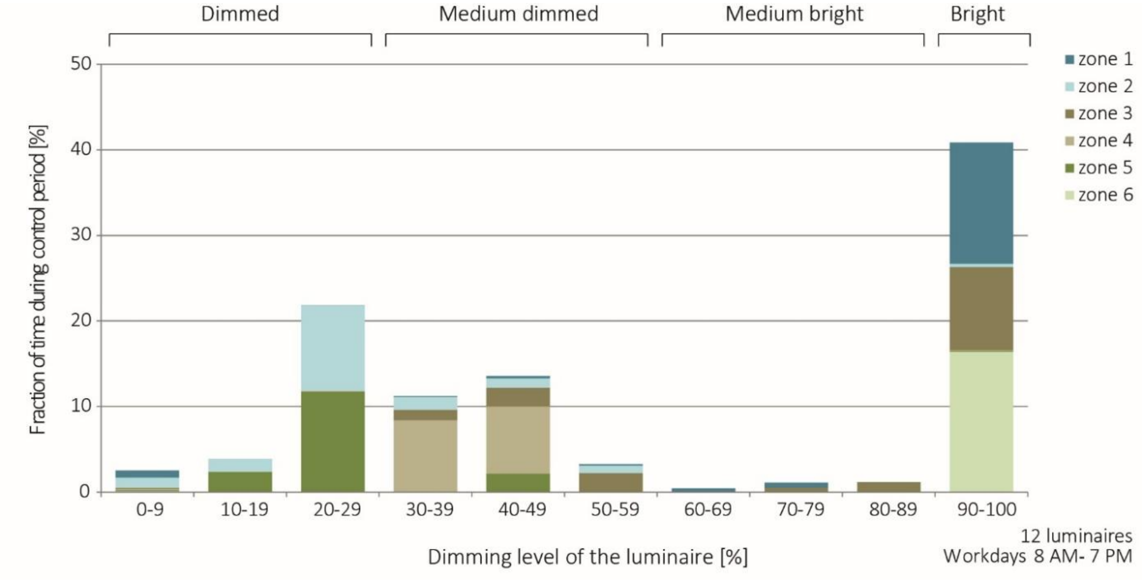


Figure 11. Dimming levels of the luminaires in fraction of time of the 6 weeks user-control period.

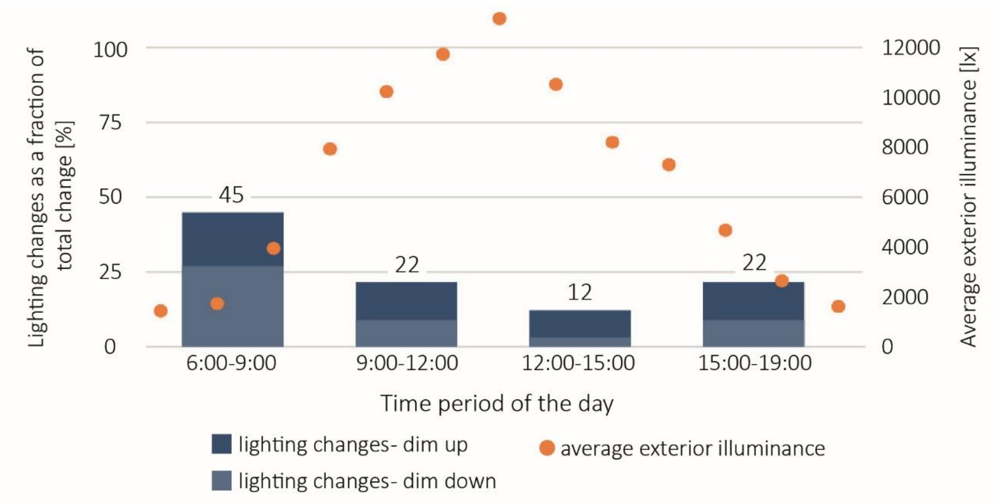


Figure 12. Light control actions of the users over the course of a day – fraction of lighting changes of total actions in 6 weeks.

During the study, HOBO sensors were placed on the desks and used to measure the desk illuminance levels. Figure 13 presents the frequencies by which illuminance levels where measured by the HOBO sensors (including daylight contribution), including data of week days from 8 am to 7 pm during the six weeks without control and six weeks with user control. As can be seen in the chart, user control conditions 2 and 3 are shifted towards lower illuminance values compared to conditions 1 and 4. Due to the spatial sensitivity of the HOBO loggers, the distributions can only be analysed relative to each other. The data does not exclude desks that might have been temporary unoccupied during this timeframe.

The power consumption of the luminaires during the reference period of six no-control weeks was compared to the power consumption of the luminaires during the six user-control weeks. The results are presented in Table 3. The table presents the energy consumption by the lighting of the combined no control and user control conditions for the 12 luminaires that were controlled by the users, as well as for all 16 luminaires in the testbed, which includes the four wall adjacent luminaires which were not controllable by the users.

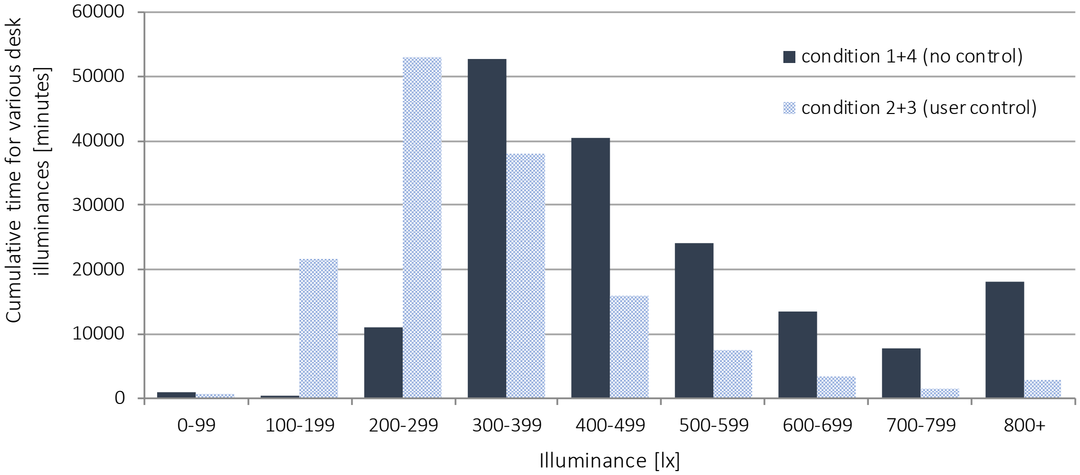


Figure 13. Desk illuminance distributions, including daylight contribution (All weekdays from 8 am – 7 pm).

Table 3. Energy consumed by lighting during the user-control and no-control conditions.

	Condition	Total energy consumption in kWh	Weekly energy consumption in kWh	Relative energy savings in %
User controlled luminaires (12 luminaires)	User control	134.8	22.5	31.9
	No control	197.9	33.0	-
Entire testbed (16 luminaires)	User control	192.6	32.1	27.2
	No control	264.5	44.1	-

2.3.2. Subjective results

2.3.2.1. Lighting quantity and quality

The light quantity and quality were assessed weekly. The results presented here are based on six weeks no-control and six weeks user-control, using per participant an aggregated value for no control (aggregated from six evaluations) and an aggregated value for user control (aggregated from six evaluations for 13 participants, and from five evaluation for one participant, due to a missed survey item).

In both conditions, there was a tendency to report receiving a bit too much light on the desk and the PC screen, as well as a bit too much daylight specifically on the desk. However, this tendency is lower for the user-control situation compared to the no-control situation, as indicated by the data presented in Table 4. Figure 14 presents the light quantity ratings on the four-point dissatisfaction scale (Moore et al., 2004), as explained in Section 2.2.5 (Figure 10). Levels of dissatisfaction with the amount of light on the desk, the PC screen, and by daylight show to be lower in the user-control compared to the no-control condition. Statistical analyses using a non-parametric Wilcoxon Signed Ranks test shows this effect to be significant for the dissatisfaction with the light quantity on the desk (p=0.029) as well as on the PC screen (p=0.047), with both a large effect size (respectively -0.58 and-0.53, Pearson r). In the interviews, the majority of participants indicated to appreciate the possibility of dimming down the lighting as they felt the preferred dimmed lighting was “more relaxing” for their eyes. Some participants indicated to prefer bright light, for visual performance, “to avoid a gloomy office”, or “to feel more energized”. Despite the diversity in lighting preferences, the frequency in which conflict was reported in the extended surveys, remained very low with the exception of two neighbouring participants. However, also for these participants, the degree to which the conflict was experienced was rated as low in these surveys and reaffirmed in the interviews.

Table 4. Lighting quantity for the no-control and user-control condition.

	Assessment of quantity of light (1 = too little, 7 = too much)								
	On desk			On PC screen			Daylight		
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
C_{nc} (n=14[a])	4.57	0.787	4.63	4.30	0.599	4.38	4.76	0.920	4.62
C_{uc} (n=14[a])	4.05	0.598	4.00	4.07	0.586	4.00	4.50	1.121	4.08

a) Mean aggregated values per participant for six no-control (C_{nc}) evaluations (n=84) and six user-control (C_{uc}) evaluations (n=83).

A correlation was shown between the assessment of light quantity on the desk and PC screen (τ=0.771 using Kendall’s tau (p=0.000)). The importance to have control over the lights showed a statistically significant weak correlation with the perceived light quantity on the PC screen (τ=-0.300, p=0.039), but no correlation with the perceived light quantity on the desk.

Figure 15 presents the data of the light quality and glare ratings in boxplots. The quality of light was rated to be above neutral in the reference condition with a statistically significant improvement in the condition with the ability to control (p=0.096), however with a very small effect size (-0.05, Pearson r). The assessment of light quality showed a correlation with the perceived dissatisfaction with light quantity on desk (Kendall’s tau τ=-0.512, p=0.000), PC screen (τ=0.550, p=0.000), and due to daylight (τ=-0.474, p=0.001), as well as the satisfaction of participants with the level of control they had (τ=0.475, p=0.001). In the surveys, glare was reported to be experienced to a minor extent in both conditions. When occurring, it was stated to be caused by direct sunlight, not by the “brightness of luminaires” or reflections of artificial light. The experience of glare was not statistically significantly affected by the ability to control (Figure 15). The assessment of glare showed a statistically significant correlation with the light quality (Kendall’s tau τ=0.372, p=0.007) as well as the light quantity on the desk (τ=-0.333, p=0.019), PC screen (τ=-0.306, p=0.033), and due to daylight (τ=-0.481, p=0.000).

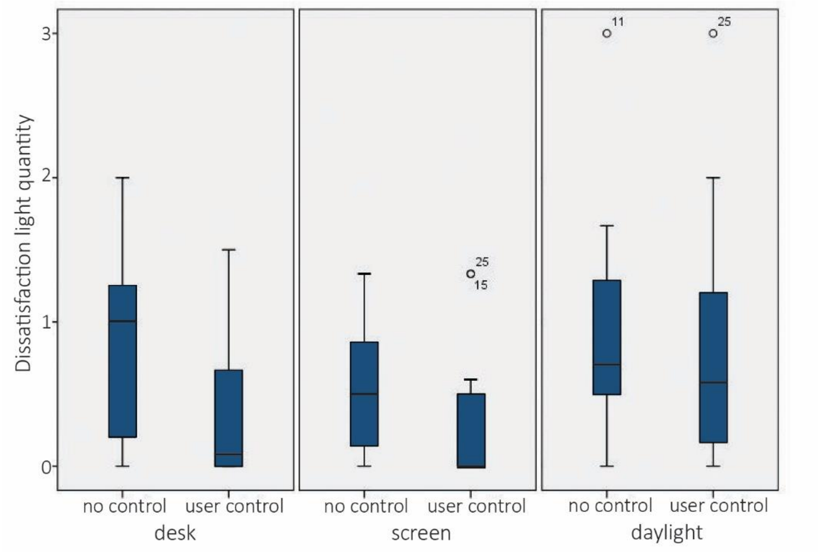


Figure 14. Boxplots of dissatisfaction with light quantity in no-control and user-control condition, based on n=14 (aggregated per participant from six no-control (C_{nc}) evaluations (n=84) and six user-control (C_{uc}) evaluations (n=83)

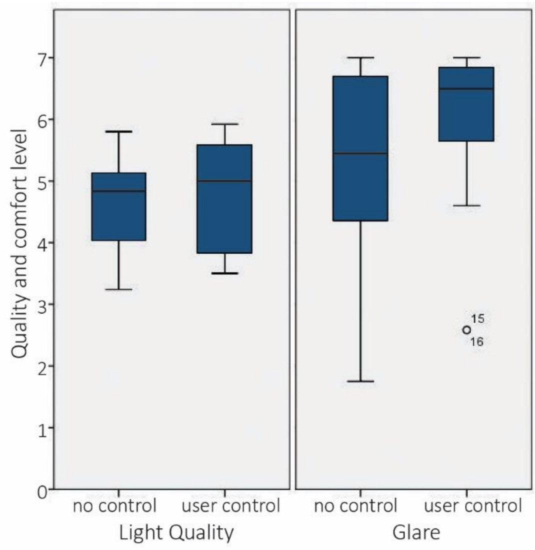


Figure 15. Boxplots of light quality assessment and perceived glare in no-control and user-control condition, based on n=14 (aggregated per participant from six no-control (C_{nc}) evaluations (n=84) and six user-control (C_{uc}) evaluations (n=83).

2.3.2.2. Environmental conditions

The environmental conditions were assessed by the participants as part of the extended survey at the end of each 3-week period, resulting in two evaluations of a no-control period and two evaluations of a user-control period.

The air quality in the office was rated as satisfying with no significant difference between the user-control and no-control condition. In both conditions, the office was rated to be a bit too noisy, with no significant effect of controls. Participants stated in the interviews to be disturbed mainly by people passing by the open office and having loud discussions. The temperature in the office was rated around neutral, with a significant effect for controls (p=0.026) with a large effect size (-0.60, Pearson r) when comparing the average temperature evaluation in the no-control condition to the user-control condition. In both no-control periods, participants rated the office to be warmer than they preferred, where in the period when they did have control they felt more neutral about the temperature. However, the perceived temperature ratings of the survey did not show a correlation with the survey results of the perceived level of control over light people felt they had during the study nor with the satisfaction with the level of control. Results are shown in Table 5. The change in perceived temperature might be caused by the actual indoor temperature. The logged average indoor temperatures differed slightly between the conditions being 23.2°C, 22.6°C, and 23.1°C for the first no-control, the user-control and the second no-control condition respectively (including workdays from 8 am to 7 pm, loggers placed on the desks). The 0.5-0.6°C lower average indoor temperature in the user-control condition was likely caused by the lower sun radiation hours in the user-control period compared to the first and second no-control periods.

Table 5. Assessment of environmental comfort during the user-control and no-control condition.

	Air quality (1=very dissatisfied, 4=neutral, 7=very satisfied)			Acoustics (1=too noisy, 4=just right, 7=too quiet)			Temperature (1=too cold, 4=just right, 7=too warm)		
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
C_{nc} (n=14[a])	5.14	1.379	6.00	3.25	0.753	3.00	4.50	1.056	4.00
C_{uc} (n=14[a])	5.14	1.167	5.25	3.50	0.734	3.50	3.96	1.100	4.00

a) Mean aggregated values per participant for two no-control (C_{nc}) evaluations (n=28) and two user-control (C_{uc}) evaluations (n=28)

Table 6. Measured environmental conditions during the first no-control, the user-control and second no-control conditions.

	Average indoor temperature [°C] [a]	Average outdoor temperature [°C] [b]	Sun radiation [hours] [b]
C_{nc} – period 1	23.2	12.8	4.5
C_{uc} – period 2+3	22.6	8.8	2.1
C_{nc} – period 4	23.1	4.4	3.5

a) Based on temperatures logged on workdays from 8 am to 7 pm, measured with HOBO sensors placed on the desks, b) based on daily average sun radiation data for workdays, KNMI weather station Eindhoven

2.3.2.3. Mood

At the end of each experimental period, an evaluation of participant mood was included in the extended survey. Mood was herein evaluated using the dominance, arousal, and pleasure scale of (Russel & Mehrabian, 1977). Unlike Newsham et al. (2004a) and Boyce et al. (2006a), this study did not show a statistically significant effect of personal control on the mood of participants. In the interviews, some participants indicated to find it difficult to rate their emotional state in the surveys. The reasons given were the complexity of the emotional states described in the survey items, and the fact that they were not used to reflect on their emotional state in the requested level of detail.

2.4. Discussion

In this study, personal lighting control was evaluated in a shared open office environment by means of a longitudinal field study. The strengths and limitations of the study will be discussed in this Section.

2.4.1. Profiles

Based on the illuminance values set by the users during the control condition, the office could be divided into three different brightness zones: zones that are predominantly bright (with luminaire dimming levels of 90-100%), dimmed zones (with luminaire dimming levels of 0-30%), and intermediate zones (as illustrated in Figure 11). The set lighting within these zones did not show large deviations outside the labelled category. This suggests that users within a zone classify themselves in a light preference category and perform their control actions consequently in that part of the dimming range, which is confirmed by the users in the interviews. However, since control is shared, the placement of a zone in one of the categories can either be the combined preferred lighting of the different users sharing the zone, or the preference of the more dominant, sensitive, or critical user in the specific zone. In the latter case, the category placement does not represent the less or non-active user of that zone. Therefore, based on this study, the classification in the categories is concluded on a zone level, and not for individual users. Interactions and classifications of individual users are further explored separately (Despenic, Chraibi, Lashina, & Rosemann, 2017) and will be discussed in Chapter 3.

Two third of the lighting control actions at the start of the day were to dim lighting down, where only little more than half of the actions at the end of the day were to dim up. The control actions of the morning were therefore not only a response of the "typical" end of the day (higher dimming level) setting, but also a response to a lighting situation created during the day. Additionally, changes were not made daily, and performed by only a subset of participants.

2.4.2. User satisfaction

The reference condition without light control offered lighting much better in line with the conventional recommendations regarding task illuminance levels than the condition with light control. However, the condition in which users were offered light control was evaluated by the participants to have a significantly better "light quantity" on the desk as well as on the PC screen. This was also expected based on the evaluations of Moore and colleagues (2004) in buildings with and without light control, that showed similar results. In the conditions without controls, users on average evaluated the light quantity to be more dissatisfying and the office to be too bright for their preference. Even though it is debatable whether personal control of the task influences the brightness perception of the offices space. The majority of the control actions were performed when exterior lighting conditions were low, at the start of the day when users entered the office space, and at the end of the afternoon. It may be argued that the improved satisfaction with the light quantity could be caused by just the presence of the controls, regardless of their usage. As shown by Sadeghi and colleagues (2016), the acceptability of visual conditions can be influenced by the occupant's perception of control. However, the shift to lower luminaire dimming levels in the user-control condition supports the suggestion that the positive effect is not caused by solely the presence of control.

The condition with user control was also evaluated to have a significantly higher quality of light. Even though the user-set lighting created dimmed and bright zones in the office space, users did not experience lighting in the space as unpleasantly non-uniform. They could be influenced by the absence of extremes in luminance ratios or by the wall adjacent luminaires being fixed at the default 60% dimming level during the user-control condition to maintain a sufficient and uniform wall illuminance.

No relations were found between light quantity and quality evaluations and the age of the participants. The environmental satisfaction and the mood of the participants were not affected by the presence and use of light controls, neither positively nor negatively. A positive effect was expected based on the studies of Newsham and colleagues (2004a). Cultural differences could have played a role. Some participants did indicate to have experienced difficulties with the mood survey items. This challenge could be partially caused by cultural or personal awkwardness of sharing emotional states in the survey. Despite anonymous participation in the study, this could be reinforced by the personal contact with the researchers during the interviews, and the fact that the participants were part of the same organization as the researchers.

Even though a significant difference in temperature assessment was found between the user-control and the no-control condition, the data does not show the perceived level of control over lights to have an influence on the perceived temperature. The outdoor climate data showed a lower number of sun radiation hours during the user-control period compared to the no-control period, which could have influenced the indoor temperature evaluations of the participants.

2.4.3. Conflict or burden

Offering control to achieve individually preferred lighting, also introduces the risk of disagreement between users due to different preferred light settings. This disagreement of preferences can cause experience of conflict. In this study, the experience of conflict, rated by surveys, was limited to two people (out of 14 participants) working in the same zone (zone 5). In the interviews, different participants stated that they noticed lighting changes when they were made by colleagues as well as having the impression that their initiated changes were noticed by their colleagues. Small, slow, or gradual light changes were found more acceptable and in general not perceived as negative by the observer, while fast and large light changes were less appreciated. This suggests that there is a difference between the acceptance of a set light level and the acceptance of the dimming speed to achieve this light level. In the interviews, none of the participants stated to have experienced serious discomfort caused by fast or large light changes. It could be that it is not the changed light level that leads to lower appreciation, but the distraction from the office task caused by the noticed light change.

Participants referred to different indicators in their visual field that triggered them to notice the light changes. Some participants indicated visible dimming of a light source itself. Others mentioned triggers like a perceived brightness change in their surroundings, a noticeable change of their desk light level, or a shift of the selected dimming level on their user interface. Due to the desk dividers in the office space, as shown in Figure 6, noticeability of changes at the opposite desks might be limited, e.g., the neighbour exercising the control action, or a change in the light level at the opposite desk.

Users who intended to set a preferred light level were cognisant of other people in their vicinity. This consequently influenced their behaviour. Even though these changes were generally acceptable, neutral comments were still made when observed. This triggered some users to set their preferred light level in a non-noticeable way, i.e., slow and gradual. A difference might exist in an acceptable dimming speed for the observer and the user performing the action, likely influenced by personal character as well.

The size of the control zone may influence the risk of conflict, as was also shown by Moore et al. (2000). The more people that need to reach a consensus on preferred light level, the higher the risk of conflict situations occurring. Indications from users in the interviews showed a diversity in their lighting preference and sensitivity. Some participants pursued a dark environment by closing the blinds and dimming the lights, while other participants preferred a very bright environment, or indicated not to have an outspoken lighting preference. 70% of the participants did indicate to prefer the experienced consensus control over no control at all.

All participants in this study were at the same corporate hierarchical level. A reporting difference may influence the perceived conflict of users as well as the tendency to use the controls in these situations.

Providing users with required social information through the user interface could increase the users' awareness about their social context. This approach is referred to social translucency or designing for awareness, and could assist users to better estimate the impact of their actions on others (Erickson & Kellogg, 2000), to limit or avoid conflict.

2.4.4. User interface effect

Control was offered with a range from 1 to 100% luminaire output (100% corresponding to an average work plane illuminance of 500 lx from artificial light when all luminaires are on). In previous studies, it has been shown that the range of the offered control as well as the anchor point of the user interface to have an influence on the selected preference of the user (Logadottir, Christoffersen, & Fotios, 2011b). Offering a different range is likely to influence the preferred absolute illuminance, but the distribution of preferences between people will still hold. When the user-control condition was introduced, the controllers were set at an anchor point of 60%. Some users indicated to be pleased with the extended range they were offered after the introduction of controls, assuming the anchor point to resemble the default setting of the no-control condition. Similar to the range of the control, the start position of the control might have influenced the selected preference. Absolute values of the preferred illuminance should therefore only be interpreted in the context of this study. Results from Uttley et al. (2013) underpin the assumption that even though an anchor point and range do influence the selected light level, they do not influence the satisfaction of the users with their light preference.

2.4.5. Limitations of the study

The study of Moore et al. (2002b) has earlier suggested that people perceive control as important, that the perception of control could be improved through smaller control groups, and with that, the satisfaction with the degree of control. Luminaire control groups were created perpendicular to the façade, following a desk layout that gave neighbouring co-workers an equal level of control. By doing so, it was not possible to separately control the areas near the facade from the areas further away from the windows. Even though the office is only 5.0 m deep, participants sharing a zone were exposed to different lighting conditions due to different daylight contributions on their task surface. This could have influenced participants to take greater consideration of each other. A different partitioning of zones could have influenced among others the satisfaction of the participants with light quantity and the actually selected light levels.

To capture the small anticipated positive shift in user evaluations from neutral or satisfied correctly the study was designed as a longitudinal study. To deal with the changing outdoor conditions during the study as well as the effect of introducing or removing the controls, a counterbalancing study design was chosen. Due to the summer holiday period and the associated absence of the participants, the experiment started in September. The reference no-control condition covered the longest days of the study in the first experimental period in September as well as the shortest days in the last experimental period in December. The user-control condition covered the autumn days during the second and third experimental periods. Offering user-control to participants earlier or later in the year could have influenced the use of the light controls based on a difference in available daylight.

2.5. Conclusions

In this study, it was shown that consensus control improved user appreciation of office lighting in an open office, measured by improved satisfaction. Even though the controllable light was shared with colleagues in the same zone, consensus control resulted in higher satisfaction compared to the condition without control and a fixed average work plane illuminance of 500 lx. Higher satisfaction is demonstrated by the amount of light on the users' desk and PC screen as well as with the quality of the light when offering control. In the condition with light controls, the average preferred illuminance values were shown to be lower than the fixed 500 lx work plane lighting, resulting in 27.2% lower energy usage by lighting in the testbed of this study. Consensus control did not introduce a negative effect on the environmental satisfaction or the mood of the office users.

Users did show different lighting preferences, resulting in a few conflict cases. Preferences were set for the task but in interviews also expressed regarding the complete office environment, e.g., "I like a bright and energizing office atmosphere".

The light changes due to personal control were regularly noticed by co-workers in the space but rarely rated as disturbing. However, the noticeability did influence users in their choice to adapt the light. Differences in personal character distinguished users that perform a control action, regardless of others noticing it, from users that are more hesitant to express their light preference and avoid control actions that are noticed by others.

Based on the lighting preference and personal character, it is hypothesized that users can be subdivided into profiles. Considering these profiles offers opportunities to limit conflict. This supports the requirement that automated control systems need to be capable of taking individuals' profiles into account, rather than only general information such as the time of day.

Chapter 3

3. Lighting preference profiles of users

This chapter is based on the following publication:

M. Despenic, S. Chraibi, T. Lashina, A.L.P. Rosemann, Lighting preference profiles of users in an open office environment, Build. Environ. 116 (2017) 89-107.

Offices are transforming into multi-user, open space environments to stimulate interactions between people and optimize the usage of the office space. Due to design practices, lighting systems in these multi-user environments are implemented as a regular grid of luminaires that often does not match the furniture layout. Consequently, purely personal control over general lighting is not achievable in most cases. As a result, a single luminaire affects several neighbouring desks, creating shared lighting controls and conditions. Therefore, providing satisfying lighting conditions to everyone becomes a challenge. In this chapter a first method is proposed for modelling lighting preference profiles of users based on their control behaviour and preference information. Objective measurements and subjective data obtained in two field studies showed that users can be profiled based on their control behaviour, regarding the characteristics activeness, dominance, lighting tolerance, and dimming level preference. The results showed significant differences between lighting preference profiles of users. In addition, a first method is proposed for discovering submissive users and triggering them to express their preferences in order to derive their profiles as accurately as possible. This will help to secure users' comfort with lighting by offering lighting conditions satisfying their preference. By knowing the lighting preference profiles of users, the probability of conflict between users can be predicted and minimized.

3.1. Introduction

Offices in modern, commercial buildings are rapidly transforming into multi-user environments that stimulate a collaborative way of working. Closed offices are converted into open offices, low partitioned spaces, or flex environments where users do not have assigned workplaces. Furthermore, the Gensler model, envisioned to enhance user satisfaction and productivity by offering activity-based workplaces is gaining popularity (Gensler, 2008). Employees make transitions more often between work modes at their desks and between locations compared to traditional ways of working (Appel-Meulenbroek et al., 2015; Knoll, 2011; Leesman, 2016). Standards provide lighting recommendations to ensure a comfortably lit office environment (Illuminating Engineering Society, 2011; NEN-EN 12464-1, 2011), but they do not take into account that lighting requirements between neighbouring users might differ due to their mood, activity, or preference. Providing everyone with satisfying lighting conditions becomes a challenge.

3.1.1. Benefits of personal lighting control

Several studies showed that lighting preferences of people differ significantly. In a windowless open-plan office with cubicle workstations, Veitch and Newsham (2000b) evaluated the preferred lighting conditions of 94 participants when performing office tasks. The study showed individual lighting preferences for horizontal illuminance to range between 83-725 lx. In another laboratory study of Newsham and colleagues (2004a), participants worked in a mock-up office for one day. They had no control over lighting until the latter half of the afternoon, where they chose desktop illuminances ranging from 116 lx up to the maximum achievable 1478 lx. In the laboratory study performed by Boyce et al. (2000) in windowless offices, 18 participants were offered controllers to dim the light output of the luminaires in a large control range (12-1240 lx) or a small control range (7-680 lx). The study showed that for the same task, individuals chose different illuminance levels. The median workstation illuminance chosen ranged from 110-1230 lx for the larger and from 80-630 lx for the smaller control range. In a later study by Boyce et al. (2006b), 57 temporary office workers spent a day in an office with the freedom to adjust the lighting of the cubicle they occupied. The study showed individual preferences to range from 252 to 1176 lx. A longitudinal field study of Moore et al. (2003b) included 45 office workers in four different buildings in the UK, where occupants were able to vary the illuminance on their workplace. The study showed a mean daily workplace illuminance of 288 lx, with individual averages ranging from 91 lx to 770 lx.

Due to the broad range of individual lighting preferences, it is a challenge to create satisfactory lighting conditions in a multi-user space by providing fixed lighting conditions to all users. With a fixed illuminance level installation, Boyce and colleagues (2006b) demonstrated that only up to 65% of occupants would be within 100 lx of their preferred illuminance. This percentage can be increased by providing personal lighting control for office users.

Benefits of personal control are not limited to satisfaction of individual illuminance preferences. Studies have shown that when users can adjust the illuminance level on their desks, it has a positive effect on their satisfaction with the overall environmental conditions (Boyce, Veitch, Myer, & Hunter, 2003; Lee & Brand, 2005; Moore et al., 2004; Newsham & Veitch, 2001; Newsham, Veitch, et al., 2004a; Veitch et al., 2007; Veitch, Charles, Newsham, Marquardt, & Geerts, 2003; Veitch et al., 2010; Veitch, Geerts, Charles, Newsham, & Marquardt, 2005), with lighting quantity and quality (Boyce et al., 2006a), on mood, motivation and vigilance (Veitch et al., 2008), and on their productivity (Boyce et al., 2006a; Newsham, Veitch, et al., 2004a; O'Brien & Gunay, 2014). Besides, occupants who have more opportunities to adapt their environments to their own needs will less likely experience discomfort (O'Brien & Gunay, 2014). Having a workspace without some degree of control over the environment leads to increased discomfort and stress (Vischer, 2007). Therefore, personal control for office lighting is believed to enhance users' satisfaction and comfort in modern office buildings.

3.1.2. Challenges in open office environments

Due to the design practice for office lighting systems, multi-user environments are commonly deployed with a regular grid of luminaires that often does not match the furniture layout. Subsequently, in most open office spaces it is not possible to offer desk specific lighting when only using the ceiling mounted general lighting system. A single luminaire would in many cases influence several neighbouring desks, thus the lighting conditions as well as the lighting controls have a shared nature and are referred to as *consensus control*. The common practice for control in such cases, is to combine luminaires into control groups, such that all luminaires in one control group act as one. Multiple users get shared control over a group of luminaires affecting their desks. Analyses of 14 open-plan offices by Moore et al. (2002a) showed that occupants become increasingly reluctant to make changes to the lighting as control groups become larger. The researchers suggested that the control group size should be as small as possible, to enhance user satisfaction and maximize the benefits of lighting control, while equally empowering users. The follow-up study showed that even when sharing controls, the majority of users experienced a benefit of having controls (Moore et al., 2004), with satisfaction with lighting quality and quantity rated higher than in situations without control. In a field study evaluating personal control in an open office space, similar results for improved lighting quality and quantity were demonstrated (Chraibi et al., 2016). However, a small portion of the users did indicate to have experienced difficulties in finding consensus with colleagues in the same control group, due to opposing lighting preferences. If preferences of different people that share a system do not align, conflict can come to exist. Conflict is defined as "the interaction of interdependent people who perceive opposition of goals, aims, and values, and who see the other party as potentially interfering with the realization of these goals" (Easterbrook et al., 1993).

When asked to express a preference at the end of the study, 10 out of 14 users opted for shared controls, one preferred a situation without controls, and 3 did not express a preference.

The difficulties in finding consensus might be caused by differences in individual preferences for lighting as shown in the previously mentioned studies. In interviews, users who participated in the performed preference study (Chraibi et al., 2016) indicated preferences ranging from bright light, which made them feel more energized, to dimmed light, which was more relaxing for their eyes. A group of people indicated not to have a specific preference beyond being able to perform a visual task. Some indicated not to be critical towards a light level, and some indicated to more quickly experience discomfort glare than their colleagues. Influenced by the users' character and sensitivity to light, a difference might exist in how critical users are in their selection of preferred lighting. User data logs of the light controls demonstrated different ranges of illuminances that users accepted without initiating a change. Some users showed a broad range of selected luminaire dimming levels, while others demonstrated more invariable choices. Similar to what was shown by O'Brien and Gunay (2014), a conflict avoiding behaviour was observed in the study of Chraibi et al. (2016). Some users would not perform a lighting control action to avoid potentially interfering with the preference of their neighbours, eventhough the experienced setting did not match their personal preference. Some users used small steps in their control actions so that present colleagues would not observe the change, others performed actions when colleagues were absent. O'Brien and Gunay showed that people are greatly affected by the presence of others when considering taking actions that might cause discomfort to colleagues. Differences in people's personalities can also influence how they interact with their environment in the office. Some people might be more dominant or vocal and feel less hesitation to express their preferences, while others might show a more conflict avoiding behaviour.

3.1.3. Research motivation

Personal characteristics are believed to influence users' preferred and selected lighting, when given a choice. Various studies evaluated occupants' lighting preferences and the effect of their personality on interactions with lighting systems (Heydarian, Carneiro, Gerber, & Becerik-Gerber, 2015; Heydarian et al., 2016). Newsham and colleagues (2008) showed that there is a great variation within individuals around their preferred illuminance values, and many participants chose illuminances that differ by more than 25-50% at various times of the day. Boyce and colleagues (2000) also found a large difference between occupants' control behaviour. Some people adjust illuminance levels a little, while others adjust illuminance levels over the entire available range. The frequency of adaptive measures significantly decreases in shared offices compared to private offices, due to occupants' timidity to take adaptive actions that would potentially disrupt the comfort of others (O'Brien & Gunay, 2014). Moore et al. (2000) showed, people who experience conflict to have a decreased satisfaction with lighting quality and to be more likely to avoid using controls than those who do not experience conflict. This study of Moore and colleagues also showed that stronger personalities dominate in conflict situations.

Based on light preference data of users, obtained in two field studies, users are profiled based on their activeness, tolerance, dominance, and preference for personal control and lighting level.

It is hypothesized that intolerant users (with regard to deviation from their light level preference) will be more active to achieve their preferred lighting, unless they are submissive in relation to their neighbours in the same luminaire control zone. In those situations, the risk of dissatisfaction is high. Tolerant users, who will prefer a broad range of selected illuminance levels, are expected to be less active in their lighting control behaviour and will have a lower risk of dissatisfaction. Submissive users are expected to be in general less active than dominant users, due to their conflict avoiding character.

Based on the zone luminaire output and the lighting preference profiles of the users occupying a control zone, the control zones can be classified. Knowing the control zone classification allows for automatic evaluation of the users' satisfaction. Subsequently, via appropriate control actions, users' satisfaction with the lighting conditions in that zone can be enhanced. This knowledge also allows the prediction of potential conflict between users in the same control zone and to facilitate the process of making consensus choices to improve overall user satisfaction.

In this Chapter a first method is proposed for modelling lighting preference profiles of users and classifying control zones based on users' control behaviour, to be able to offer satisfying lighting to a group of users. Cases that require additional feedback from the users are explored to secure or enhance users' comfort.

3.2. Methodology

In 2013 and 2014, two field studies have been conducted in an open plan office to evaluate whether benefits of personal control would still be observed when applied as consensus control in an open office environment (Chraibi et al., 2016; Lashina et al., 2019). In these studies, objective and subjective data was collected concerning the experienced lighting environment and the usage of the individual light control devices. Both studies were conducted as field studies to explore and validate user benefits of using lighting controls in a realistic setting. A longitudinal design allowed social dynamics to evolve during the course of the studies.

3.2.1. Testbed

The two field studies were conducted in an open office with a south facing façade and located on the 4th floor of an office building in the Netherlands. Figure 16 shows a schematic representation of the open office testbed. The façade consisted of four segments of 2.5 m high and 3.2 m wide windows. For daylight and direct sunlight management, the testbed provided motorized internal as well as external blinds. The external blinds could be set to manual or automatic control mode, and the internal blinds could only be controlled manually. The internal as well as the external blinds were divided in four controllable segments mapped to the windows, with windowsill mounted control interfaces per segment. The interfaces for the segments were for general use and the control means for the blinds did not change during the test. The external blinds were lowered automatically when the rooftop light sensors detected illuminances higher than 16000 lx and raised at fixed times (9 pm) or when the wind speed exceeded 30 km/h. The external blinds were operated in both modes but were observed to mainly be operated manually throughout both studies, primarily by the participants adjacent to the windows. The participants worked in their normal office environment. There were no instructions or other mentions of the (manual) blind control to ensure that all participants would keep interacting with the space the same way they normally would.

As in most open office spaces, due to the office layout and the predefined grid of luminaires, it was not possible to offer truly personal control over a luminaire to each user. To give the participants equal sense of control, luminaires were combined into control zones, such that one control zone would be offered to the smallest possible number of users as suggested in (Moore et al., 2002a). This resulted in combining two luminaires per zone, shown in Figure 16, leading to a total of 6 control zones with 2-3 users per zone. With this design, the control of lighting is not personal, but labelled as consensus control.

To implement the testbed, an existing lighting installation with 16 TL5 49W lamps, was modified in accordance with the study requirements. All 16 lamps were equipped with DALI high-frequency dimmable ballasts (Philips TD 1 28/35/49/54 TL5 E_+) to allow dimming of the luminaires in the six control zones. The 12 central luminaires were controllable by user interfaces. The outer four luminaires adjacent to the walls were kept at a fixed light output to maintain sufficient and uniform wall luminance. This was done to avoid sharp contrasts on the walls that could result from daylight entering the office, since sharp contrasts were shown to negatively influence the overall space appraisal (Wright et al., 1999). Combined light and occupancy sensors (Philips PLOS-CM-KNX) were mounted on the ceiling next to each of the 12 central luminaires. The lighting in the entire space was switched based on occupancy controls. When the first person entered the office, all lights turned on. After the last person left the office, all lights turned off with a set time delay of 30 minutes. In both studies, participants were offered personal user interfaces to control the lighting of their zone.

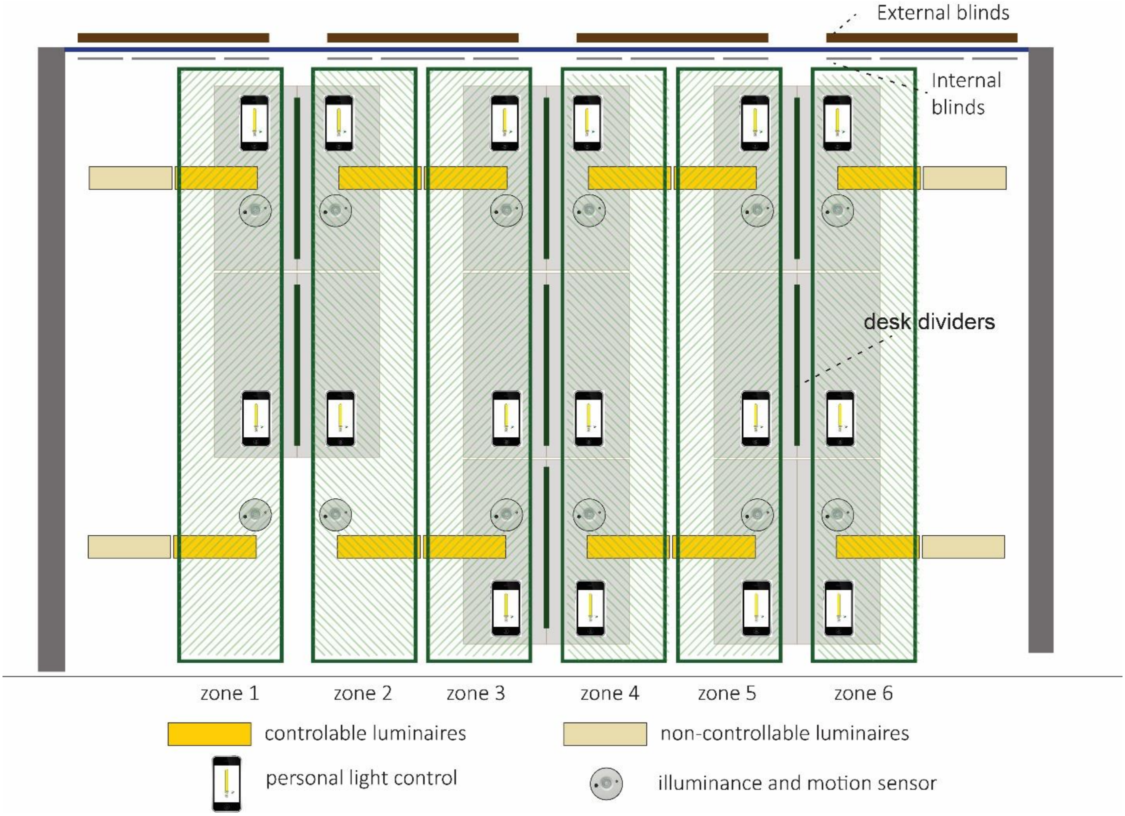


Figure 16. Schematic representation of the testbed in the open plan office. The green rectangles represent the different control zones, with two luminaires in each zone. In study 2, two additional desks were placed in the office space, visualized in the bottom right corner.

3.2.2. Study design

The data included in the analyses is based on the study conditions in which the participants were offered lighting controls, commissioned with a "memorizing" system behaviour (October 21st until November 29th, 2013 and October 27th until November 14th, 2014). During the "memorizing" personal control conditions, the default dimming level of the 12 controllable luminaires was set to 60%. This created an average desk illuminance of 300 lx by artificial lighting with the ability to be changed by each participant. Escuyer and Fontynont (2001) showed that in presence of daylight, users who work behind computer screens prefer illuminance levels between 100 and 300 lx. Moore et al. (2002a) showed that the higher the percentage of time office users spend behind a computer screen, the lower the recorded selected desk illuminance, being on average 300 lx. The results of a study performed by Reinhart and Voss (2003) showed that the probability of manually switching on lights decreases below 0.1 when 300 lx is offered to users. In accordance with these findings and provided that the participants spent most of their time on screen-based tasks, the default desk illuminance was set to 300 lx. Participants could change the artificial lighting in their control group in a range from off (*study 1*) or 1% (*study 2*) to full luminaire output (leading to an average desk illuminance of 500 lx). The luminaires within every control group stayed at the previously set dimming level until the next control action was performed. The dimming level could be overwritten by every user in a zone, at any point in time. After a change was made, the user interface was updated to present the current dimming level of the control group. At the end of each day, the last user-selected dimming level was memorized by the system and restored in the zone upon detection of presence the next day.

Besides the "memorizing" user-control condition, *study 1* also included a reference condition, in which the participants did not have lighting control. The reference condition of *study 1* was designed at the start of the study (August 5th till October 11th, 2013), and repeated at the end of the study (December 2nd till December 20th, 2013). During the reference condition, all luminaires were set at 100% output delivering an average illuminance of 500 lx on the desk surface, measured excluding the daylight contribution. In *study 2*, besides the reference and "memorizing" user control condition, three additional conditions with different control strategies were explored and evaluated (Lashina et al., 2019). *Study 2* started with the reference condition similar to the reference of *study 1* (July 28th till August 22nd, 2014), luminaires delivering an average illuminance of 500 lx, but with the use of daylight harvesting, dimming luminaires when due to daylight contribution the desk levels exceeded this minimum value. This was followed by a second reference condition (September 1st till September 19th, 2014), where all luminaires were set to deliver a minimum illuminance of 300 lx average on the desk surface, measured excluding the daylight contribution. Using daylight harvesting, luminaires were dimmed when due to daylight contribution the desk levels exceeded this minimum value. Besides the "memorizing" user-control conditions, a "forgetting" user-control condition (Sep 29th till October 17th, 2014) was experienced, where the user set dimming level was reset daily. The study was ended with a "set-point controlled" user-control condition (November 24th till December 12th, 2014), where the users' control actions adjusted the set-point of the daylight harvesting system. In between conditions, 'transition weeks' were designed in the protocol. Figure 17 shows the complete study timelines together with the periods of the study protocol included in this analysis. Results of the other conditions are presented separately in (Lashina, Van der Vleuten-Chraibi, et al., 2019).

In *study 1,* each participant had a widget installed on their PC as well as an iPod Touch device on their desk, both running a light control application (Figure 18a). The application visualized a slider to control zone lighting from 1% to 100% of the maximal luminaire output, and a button to turn lights off. In *study 2* participants received an iPod Touch device with a comparable light control application, to control zone lighting from 1% to 100% of the maximal luminaire output (Figure 18b). Incorporating the usability feedback of *study 1*, the user interface was updated for *study 2*, leaving out the "off" button. The perceptible step between the lowest dimming level of the luminaire group and the off-state was perceived as too large. Users also felt resistance to initiate well perceivable light changes or to create "dark" ceiling spots, believing that their co-workers would not appreciate this. Due to the limited use, the button was not included in the updated controller of *study 2*.

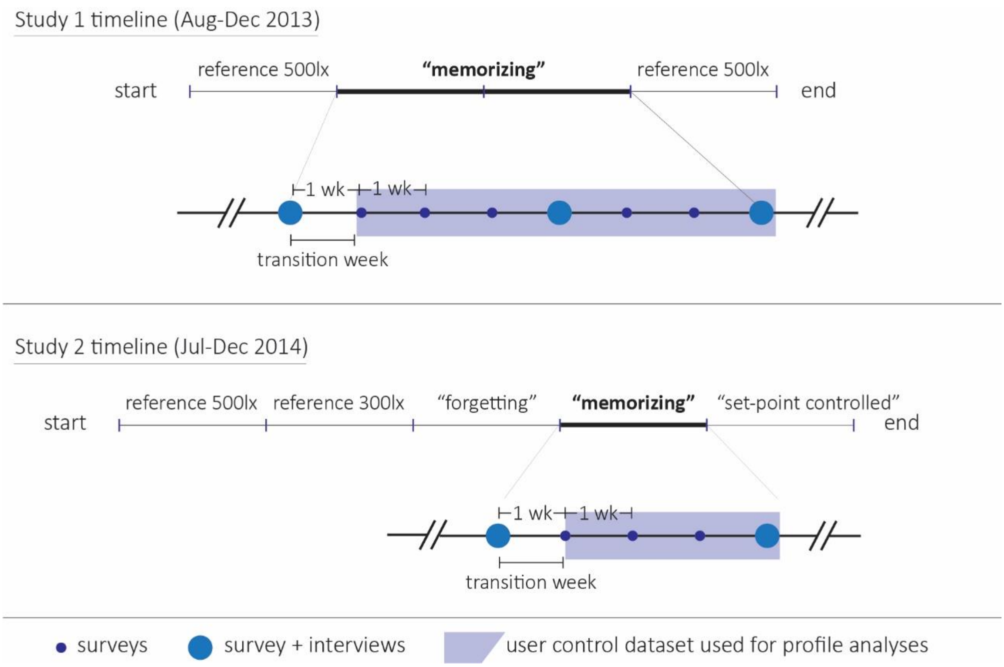


Figure 17. Timeline of study 1 and 2 with used datasets marked, upper bar representing the complete study timeline with all conditions, lower bar zooms in on the analysed "memorizing" conditions of both studies.

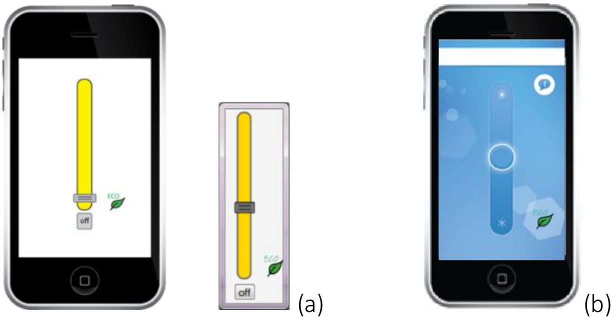


Figure 18. Light control application of study 1 on an iPod Touch and a widget (a), and of study 2 on an iPod Touch (b).

3.2.3. Measurements

The objective measures consisted of data logging from the luminaires and the user interfaces. During both studies, log files were created of the light output of the luminaires (logged every 1-minute). These are translated into logs of the relative light output, where 100% represents an average desk illuminance of 500 lx from electric lighting, excluding the daylight contribution. The relative light output of the luminaire will be further referred to as the dimming level. Log files of the user actions consisted of the user-selected dimming level, ranging from 0-100% in *study 1* and 1-100% in *study 2*. The first week of user-control, labelled as 'transition week' in Figure 17, has been excluded from the analyses due to a novelty effect. During the 'transition week', users experimented with controls much more, resulting in a deviation in the behaviour with the controls compared to the rest of the user-control condition. User actions were initiated by the users themselves, thus no predefined logging rate existed. Actions were logged at the moment they took place. Since users often performed several actions per minute while trying to find the appropriate lighting conditions, actions within a time window of five minutes were filtered out. The assumption is made that only the last user action represents the preferred illuminance. Only these last actions are included as meaningful data points for further processing.

The subjective data used for the analyses has been collected via online surveys and interviews. During the entire length of both field studies, users filled in surveys on a weekly basis. Survey questions were presented in English with a Dutch translation underneath each item. The survey questions regarding the perceived light quantity and the frequency and degree of conflict, due to the use of the shared lighting controls, were adopted from Moore et al., (2000). The participants were asked to evaluate the light quantity from the artificial lighting on their desk on a 7-point scale, ranging from '*too little*' to '*too much*'. Besides using the scale to analyse whether lighting was experienced as brighter or darker than preferred, the assessment of light quantity is recoded into four rather than seven steps, allowing for an overall assessment of dissatisfaction with the quantity of light. This approach was chosen in alignment with the approach of Moore and colleagues (2004), in which the extremes of *'too little'* and *'too much'* are translated into '*very dissatisfied'*, the *'just right,'* middle point into *'satisfied'*, and the steps in between into *'somewhat dissatisfied'* and *'dissatisfied'*. These satisfaction ratings are used as additional input to derive the preference profiles for cases with limited user control actions.

At the end of each experimental period, after 3 or 4 weeks (see Figure 17), an interview between each participant and one of the researchers allowed for further elaboration on what was captured in the surveys. All interviews in both studies were conducted by three researchers. Each participant was interviewed by at least two different researchers during the study to avoid limiting the data to the perspective of only one researcher. Interviews delivered complementary qualitative information used to understand the data and the obtained results. In the interviews, participants were implicitly asked to describe their lighting preference relative to their colleagues. Notes of interviews were systematically digitally logged after each interview, structured based on the general topics such as blinds, artificial lighting, and controls. Data of the interviews was analysed by marking key phrases in the data set, after which concepts were identified which could be named and clustered in categories, an approach very similar to the Grounded Theory methodology. Data of the interviews is used to complement the quantitative and objective data and is presented in this Chapter together with the derived profiles based on objective data.

3.2.4. Participants

The number of participants in the study was limited to the capacity of the testbed. In *study 1* a group of 14 administrative workers was relocated to the testbed for the study duration. The participants were offered fixed workplaces in the open plan office with 14 desks (Figure 16). The participants ranged from 30 – 65 years of age (mean = 48.6, SD = 9.49), and consisted of 3 females and 11 males. They worked on their actual job tasks while experiencing the study conditions. As part of the inclusion criteria, participants were present in the office during the majority of their work time. For this experiment, this amounted to at least three days a week and at least four hours a day. Most of the participants worked eight hours a day, excluding lunch breaks. Working hours varied between 7:30 am and 6 pm. The participants were naïve regarding lighting knowledge, and they were at the same corporate hierarchical level. All participants were Dutch-speaking (as a first or second language) and had good English reading and speaking skills, therefore they had no linguistic barriers for interaction.

Due to the relocation of organizational departments, in *study 2* a second group of office workers was allocated to the testbed, which had 16 workplaces (Figure 16) at the time of *study 2*. 14 subjects participated in the study, and all had a fixed desk position. The remaining two desks, located in zone 4, were used by employees with limited presence. These users did not participate in surveys or interviews but were provided with a device for light control. Prior to the study, most group members did not share an office together or work in an open office. The group included participants ranging from students to senior employees, but none of the participants had their organizational superior in the subject group, to rule out possible conflict avoiding behaviour arising from such a situation. Participants of *study 2* ranged from 25 – 65 years of age (mean = 44.3, SD = 11.58), and consisted of one female and 13 males. Similar to *study 1,* the participants in *study 2* maintained their working habits and conducted their office tasks as usual while experiencing the study conditions. The participants had no lighting or perception domain knowledge. Thirteen participants were Dutch-speaking (as a first or second language). All participants had good English reading and speaking skills, including the employees with limited presence that were excluded from the study.

In both studies, the study design and objective were not shared with the participants beforehand. The participants were informed to be part of an evaluation regarding their experience in the open office, and would receive study details afterwards, to avoid subject bias. Participants were briefed about the lighting control option at the moment they received the user interface. Prior to the user-control condition, participants experienced a reference study condition without user control over lighting, as discussed in Section 3.2.2. During this baseline period, the participants (n = 28) could get used to the office and their neighbouring colleagues, before the lighting controls were introduced. Prior to the study, the participants were only acquainted with the control possibilities of the external blinds. Both studies were submitted to and approved by an ethics board prior to execution of the research.

3.2.5. User profiling

Profiling of users is suggested to be performed based on their light preference and control behaviour in the following ways:

- *Activeness* – The level of activity of each user can be determined based on the number of user control actions. The user's control actions are a good basis to derive the user's preference profile. Having only a few control actions of a user, makes derivation of the user's profile difficult.
- *Tolerance* – A tolerant user will select a broad range of illuminances meaning that he can work under a larger variety of lighting conditions. Contrarily, an intolerant user will demonstrate a more consistent preference for illuminance levels. When weighing users' light preference profiles to offer satisfying lighting to multiple users, the tolerance of the users should be considered. The preference of an intolerant user asks for a higher weight, meaning that the proposed illuminance level should be shifted towards the light preference profile of the intolerant user. Users with a high tolerance will less likely experience conflict.

- *Dominance* – Dominance is observed via the correlation between a user's preferred illuminance level and the prevailing luminaire output in that zone. The dominance of a user can be determined as a fraction of time the luminaire output matches the illuminance level set by that user. If the output of the luminaire is set according to the user's preference for most of the time, the user is dominant in that control zone. Submissive (non-dominant) users are intimidated by others and manifest conflict avoiding behaviour, resulting in not changing the illuminance level even when dissatisfied.
- *Preference* – The dimming level preference of a user is the control setting that is most comfortable to that user, leading to the highest satisfaction with lighting conditions. Having opposing lighting preferences in one control zone might introduce dissatisfaction of the users and pose a risk of conflict.

Users' activeness and dominance with the controls both distinguish two categories of users, the active versus the inactive user and the dominant versus the more submissive user. For tolerance and dimming level preference the number of categories are unknown. Therefore, classification of users regarding these features is done by unsupervised learning, using the *K-means clustering* algorithm (Lloyd, 1982), to infer the clusters by properly describing a hidden structure of unlabelled data. An elaborate description of the methodology used to infer the clusters as well as the methodology used to validate rightful placement of each data point is published in Appendix A (Despenic et al., 2017).

3.3. Results

Users are classified based on their personal control behaviour. Classification of control zones is based on the user profiles and the luminaire output data of that zone. It takes quantitative data into consideration and compares it with the results obtained through surveys and interviews with the participants in the studies.

3.3.1. Activeness

Each individual user's level of activity can be determined based on the number of user control actions performed. The assumption is made that a user can be labelled as active if enough input is provided by him to derive the profile. An inactive user will show a lower frequency of control actions, which makes the derivation of the profile more difficult.

The proposed method assumes that a user's profile can be derived if a user provides more than two control actions within a given timeframe. This would include an expression of a preference by a first action as well as a reflection on this first action by further actions. Together, these pieces of information form a basis to determine preference and tolerance of a user. If the number of control actions of a user is greater than two, a user is classified as *active,* otherwise, a user is classified as *inactive* (Table 7). In this analysis, the timeframe concerns the included week with "memorizing" system behaviour, being six weeks in *study 1* and three weeks in *study 2.*

Table 7. Classification of active and inactive users

User type	Per timeframe
Active	n control actions > 2
Inactive	n control actions ≤ 2

The histogram of each user's control actions during *study 1* and *study 2* is represented in Figure 19. The threshold value of two is used for separation of users into the two categories, which is visualized by the solid red line.

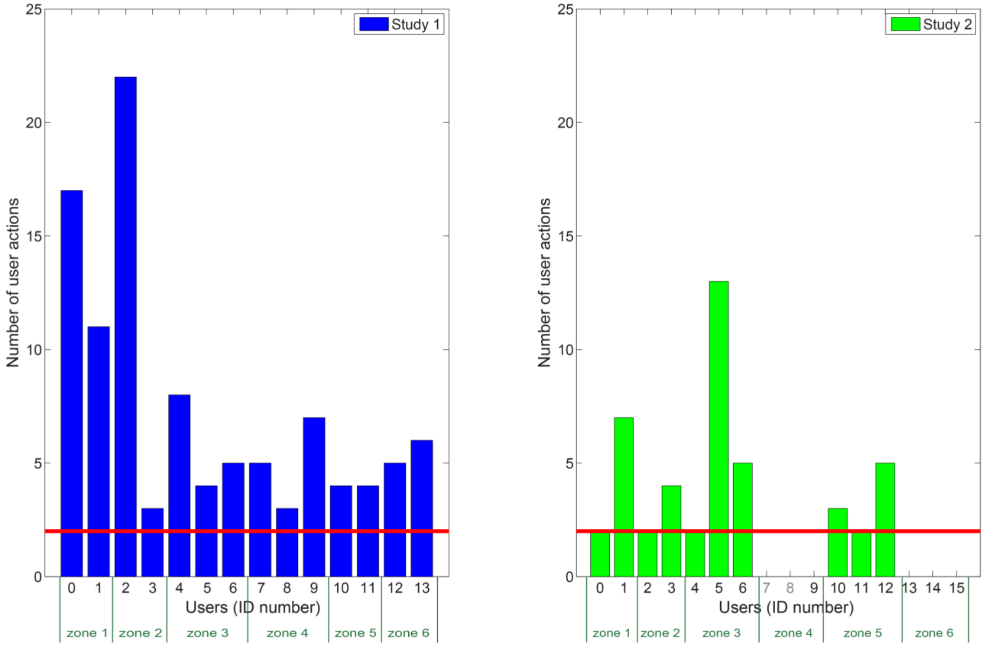


Figure 19. Number of users' control actions in study 1 (left) and study 2 (right) within the control zones. Discrimination of users' classification as inactive or active is presented by the solid line.

As shown in Figure 19, the population consisted of 14 active users in *study 1* and six active and eight inactive users in *study 2*. Some users in *study 2* (IDs 7, 8, 9, 13, 14, and 15) did not perform any control action in the study period included in this analysis. Users with ID 7 and 8 were provided with a device for light control, but did not participate in the experiment, as mentioned in Section 3.2.4. Hence, their input is not included in the analysis.

3.3.2. Tolerance

For classification of users regarding tolerance, the standard deviation of their selected dimming level is used. It is assumed that offering an illuminance level far from a user's preferred level would decrease the satisfaction of this user. The standard deviation of selected dimming levels is defined as a measure of tolerance showing how broad the range of preferred illuminance levels is. A tolerant user is expected to accept a broad range of selected illuminance levels meaning that he will perform his work under a larger variety of lighting conditions, without taking an action to adjust them. An intolerant user is expected to demonstrate more consistent choices of preferred illuminance levels resulting in a narrow range.

For obtaining the number of categories of tolerance, the combined data from *study 1* and *study 2* are used. An ANOVA test is performed to confirm the homogeneity of the data in both studies and justify combining the data sets ($F = 0.0464$ and $p = 0.8314$). Using the *K-means clustering* algorithm, two categories of tolerance are derived, the tolerant and the intolerant user (Despenic et al., 2017). Boxplots in Figure 20 present the clustering results of the data, based on the standard deviation of the selected dimming levels of the users (n=24). The crosses represent the centres of each cluster. The midpoint between the centres of the clusters is marked with the discrimination line, representing the standard deviation value of 23% for discriminating between the two tolerance categories (Table 8).

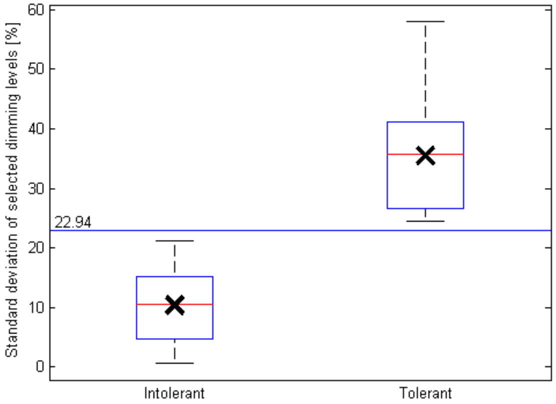


Figure 20. Clustering tolerance in tolerant and intolerant users, based on the standard deviation of users' selected dimming levels during study 1 and study 2, using the K-means clustering algorithm as described in (Despenic et al., 2017).

Table 8. Classification of tolerant and intolerant users

User type	Per timeframe
Tolerant	$SD_{\text{selected dimming level}} > 23\%$
Intolerant	$SD_{\text{selected dimming level}} \leq 23\%$

The tolerance of the users in *study 1* and *study 2* is shown in Figure 21. A standard deviation below 23%, classifies a user as *intolerant*, while a standard deviation above 23% classifies a user as *tolerant*. In *study 1*, there were seven intolerant and seven tolerant users, while in *study 2,* six intolerant and four tolerant users were observed. The remaining four participants of *study 2* did not provide any control input to derive their tolerance level.

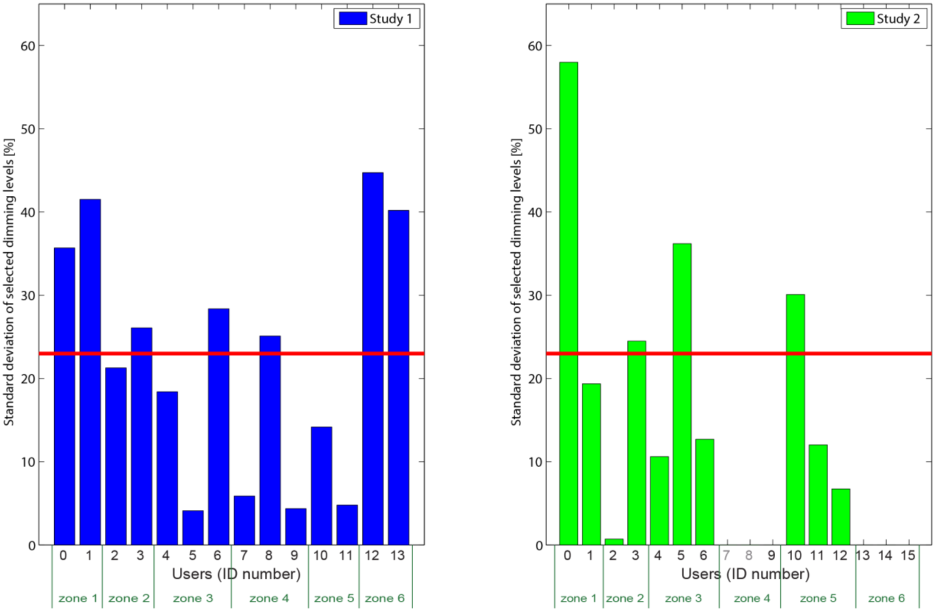


Figure 21. Tolerance of each user based on the standard deviation of the user's selected dimming levels in study 1 (left) and study 2 (right). The solid line represents the discrimination line between tolerant and intolerant users.

3.4. Discussion

In this study, data of two field studies is used to determine users' lighting preference profiles based on their lighting control actions. In this Section, the strengths and limitations of the study will be discussed.

3.4.1. Population size

To be able to classify users according to their activeness, the data related to the whole population of users (n = 28) was used. Analyses related to the users' tolerance levels and preferred illuminance levels are based on a population of 24 users from both studies, since in *study 2*, four users did not perform a single control action during the analysed periods, and a classification of those cases could not be done. The dominance of a user is classified relative to the other users in that zone (n = 2-3) since the characteristic is relative to the dominance of the specific users with whom a zone is shared. Therefore, it cannot be analysed based on the whole population of users who participated in the studies.

3.4.2. Classification

The values of classification thresholds are derived based on the data obtained in these specific studies and could have different values for a different population of users. However, a general approach for clustering and classification is presented here that could be applied to any population of users. Since the dominance of a user is determined relative to the other users within the same control zone, it can only be analysed based on the data obtained in that very zone, as previously mentioned in Section 3.4.1. Therefore, it would be inappropriate to perform clustering in order to determine the number of dominance categories in a general manner, because the analysis would be based on data from all control zones in both studies.

The proposed classes for activeness, dominance, and tolerance represent general categories and are believed to be invariant to the analysed study. Depending on the dataset the distribution of users within the categories will differ. For the preference classification, in a situation where artificial lighting could deliver more than 500 lx on the desk, a wider range of possible illuminance levels might lead to additional categories. More preference classes might lead to a higher risk of conflict (see Figure 27).

It is hypothesized that intolerant users, who prefer a narrow illuminance range, will be more active to maintain their preferred lighting unless they are submissive in relation to their neighbours in the same luminaire control zone. Tolerant users, who prefer a wide illuminance range, are expected to be less active in their lighting control behaviour and will have a lower risk of dissatisfaction. The classification results together with the results from the questionnaires showed that among 28 users, 12 users were tolerant, 13 were intolerant and for three users (ID0, 14 and 15 in study 2) the tolerance level could not be determined. Tolerant and intolerant users performed approximately the same number of control actions (75 and 72, respectively) which rejects the initial hypothesis that intolerant users will be more active.

Furthermore, it was assumed that submissiveness would suppress users to perform control actions due to their conflict avoiding behaviour. There were 17 submissive and 11 dominant users in both studies, who performed in total 61 and 88 control actions, respectively. The average number of actions per user in case of submissive users was 3.6, while in case of dominant users, it was 8 actions per user, supporting the original hypothesis. This is also in accordance with findings of previous studies (Moore et al., 2000; O'Brien & Gunay, 2014).

3.4.3. Objective versus subjective preference labels

Table 11 presented the subjective, self-assessed preference labels of the users, as well as the preference labels derived from the objective measurements. The self-assessed labels, obtained from the interview data, deviate in some cases from the labels derived from the objective measurements. The preference labels are based on calculated thresholds using the objective measurements. In contrast, users do not categorize themselves using similar thresholds but have their own way to describe their preference. The self-assessed labels were often based on personal experiences when performing visual tasks. The majority of the cases do show a match, which suggests that users do possess self-knowledge of their lighting preference when classifying it in the presented three categories i.e., *low, medium* and *high* perceived brightness preference. This also corresponds to the clustering results. Some users did describe their light preference in the interviews but did not perform any control actions in the analysed period. Their preference description could be based on the experienced lighting condition during the study but might also be based on these users' previous experiences. By asking these users for additional input in the form of their satisfaction with lighting conditions and/or preferred light level, their preference can be classified.

By taking the perceived light quantity and satisfaction with lighting conditions into account, a better match between self-assessed and derived preference labels is found (see Table 11 and Table 12). As explained in Section 3.2.3, in this study satisfaction with lighting conditions is obtained from the recoded ratings into the 4-point scale ranging from 'very dissatisfied' to 'satisfied'. This confirms that these inputs represent valuable information when profiles of inactive users cannot be derived purely based on their control behaviour.

3.4.4. Experienced conflict

In the presented analyses, it is assumed that conflict has the highest probability within the user's control zone. By measurements of the desk illuminances in the office, it is confirmed that the zone lighting has a sizeable influence on the desks illuminances within the zone beyond daylight. However, this does not exclude the possibility that conflict might occur in the user's visual field beyond his own control zone.

As illustrated in Figure 25 and Figure 26, users with ID 5 and 6 in zone 3 in *study 2* shared to have experienced moderate levels of conflict quite frequently, which is confirmed by their zone classification (see Table 12). However, the users with ID 10, 11 and 13 in *study 1* located in zones 5 and 6, respectively, also indicated to have experienced conflict, which is not reflected in the classification results. In the interviews, these users confirmed to have matching preferences with the neighbours in their own zones but opposing preferences with users in the adjacent zone as presented in Section 3.4.8. The analysis of conflict between zones is out of the scope of this analysis.

3.4.5. Limitations and possible improvements

In these studies, individual presence information of users was not available. Lighting was controlled based on overall occupancy of the office space, as explained in Section 3.2.1. Therefore, it was not possible to determine what lighting conditions each user actually experienced during the study. Having presence information would help to generate the preference labels more accurately and better distinguish between user's preference and acceptance. An illuminance level set by a particular user is clearly recognizable as his preference. If a user experiences an illuminance level set by his zone neighbours, the presence of his colleagues influences the interpretation of this data. If a user is alone in a control zone, without any social obstacles to change lighting, the illuminance level of the zone is assumed to represents the user's preference, regardless of the action holder. If a user is not alone, the prevailing illuminance level represents the user's acceptance, but might not be his preference. Distinguishing between acceptance and preference helps to recognize submissive users. Accepted lighting conditions that differ from a user's preference are an indication of submissiveness.

Another limitation is that a group action as a result of an agreement between multiple users is used as input to determine the preference of the user who performed the action. Verbal agreements reflecting the preference of multiple users are not identified. With individual presence information, this action could be identified as acceptance of the other users and preference of the user performing the action. Having additional information based on individual presence would provide more detailed information on each classification. This could lead to fewer cases where additional input from the users is needed, as suggested in Section 3.3.6.1. However, the limited data does show that from the users' lighting control actions, user's satisfaction with lighting conditions can be still evaluated and risk of conflict between users can be predicted.

In the here presented methodology, preference labels are derived based only on user's lighting control actions and luminaire output data and are independent of contextual and environmental data. Using this method, preference profiles could be determined without additional sensor data. However, people could have different preference depending on aspects such as the time of the day, weather conditions or presence of colleagues in the control zone or office space. The blinds control and with that the available amount of daylight can have a significant influence on the choice of artificial lighting condition. The profiling of the specific users could be different in situations with more or less daylight due to blinds control, e.g., by triggering people to be more active if the space has less daylight.

In the presented methodology, the activeness is determined based on a proposed threshold of two actions per user. It is arguable whether reliable classification needs more data points. Additional evaluation is needed to assess the error in profiling based on this limited number of actions. However, with a higher threshold for activeness, the proposed method stays identical, only more users might be asked for additional satisfaction data, resulting in a more reliable classification.

In the performed analyses, the conditions with a similar "memorizing" system behaviour are included. In *study 2* personal control was, besides "memorizing", also offered in conditions with "forgetting" and "set-point controlled" system behaviour. Including the user's behaviour during those conditions leads to the same classifications for six of the users. Six users that are profiled as inactive based on the "memorizing" data, show active control behaviour in one or both other conditions. For most users this does not influence their *tolerance*, *dominance,* or *perceived brightness preference* labels. Two users that are profiled as active based on the "memorizing" data, were inactive in one or both other conditions. The zone classifications are not different when considering the data of the other conditions.

The number of participants in the study was limited to the capacity of the testbed. A larger group of participants would further strengthen the proposed classification approach.

It can be observed that profiles of the users significantly differ from each other even for users in the same control zone that experienced similar environmental conditions. This confirms that satisfactory lighting conditions cannot be obtained by providing a fixed illuminance level for all users and that there is a need to take users' profiles into account when offering lighting. Knowing the profiles of the users in the space, offers the possibility to increase the satisfaction of users by automatically considering their personal as well as their neighbours' preferences.

3.4.6. Dominance

The dominance of a user is relative to the other users in that control zone. The dominance can be determined by the fraction of time the luminaire output matched the dimming level set by each user. If the user is dominant, the output level of the luminaire in the user's control zone will be set in accordance with the user's preference for most of the time. A more submissive user would hesitate to change the illuminance level even when dissatisfied with lighting conditions.

The threshold for discrimination between dominant and submissive users is chosen as the fraction of the number of users within a control zone. For a zone with 3 users the threshold would be 0.33, for example. When the user's set lighting prevails in his control zone, the user is classified as dominant. For a submissive user, the set lighting will remain unchanged for a relative time below the threshold (Table 9).

Table 9. Classification of dominant and submissive users

User type	Fraction of time
Dominant	$t_{rel,user\_set\_lighting} >$ threshold
Submissive	$t_{rel,user\_set\_lighting} \leq$ threshold

Figure 22 represents the relative time the output of the zone luminaires had a dimming level set by each user in *study 1* and *study 2*. Based on this classification, the population in *study 1* consisted of six dominant and eight submissive users, and in *study 2* of five dominant and nine submissive users among 14 participants. Users with IDs 9, 13, 14 and 15 in *study 2* did not provide any input during the study and therefore, it is assumed that they were equally submissive.

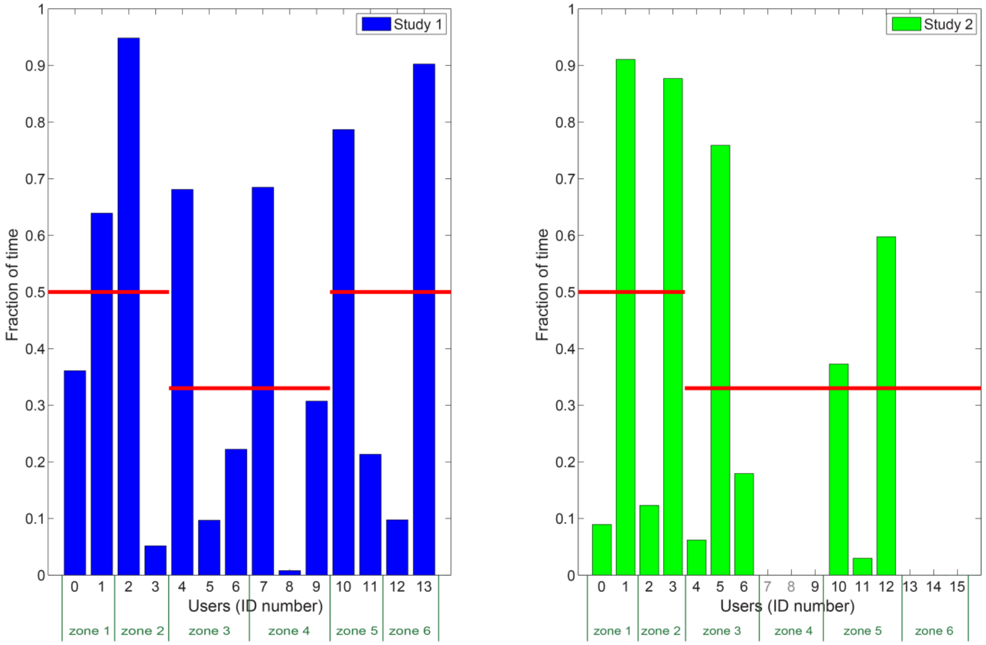


Figure 22. Fraction of time the output of the luminaire had a dimming level set by a certain user in study 1 (left) and study 2 (right) in a corresponding control zone.

3.4.7. Preference

For the dimming level preference analysis, it is assumed that users select illuminance levels that they find comfortable and most satisfying. This is confirmed by the interviews with users. Each user's dimming level preference is calculated as a mean value of the user's selected dimming levels directly resulting from this particular user's control actions. The selected dimming levels are used as input for the preference of a user, regardless of the time the set dimming level prevailed in the zone. A group action as a result of an agreement between multiple users is only used as input to determine the preference of the user who performed the action.

For obtaining the number of categories of preference, the combined data from *study 1* and *study 2* is used. Similar as for tolerance, an ANOVA test is performed to confirm the homogeneity of the data. The results confirm that the data from both studies is homogeneous ($F = 0.00021$ and $p = 0.9886$) and can be combined for derivation of the preference labels (Despenic et al., 2017).

Using the *K-means clustering algorithm,* users are categorized to have a *low, medium,* or *high perceived brightness* preference, as shown in the results presented in Figure 22. The discrimination lines between the classes of users are calculated as the average distances between the centres of the clusters, being 42% and 66% (Table 8) (Despenic et al., 2017).

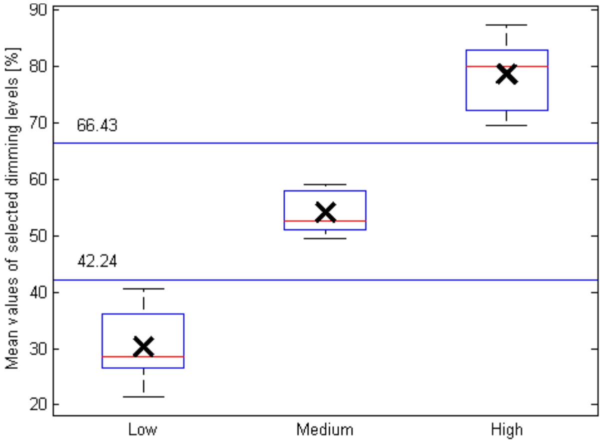


Figure 23. The result of K-means clustering algorithm based on the mean value of users' selected dimming levels in study 1 and study 2 with low, medium, and high perceived brightness preference clusters.

Table 10. Classification of perceived brightness preference of users.

User type	Mean value of user's selected dimming levels [%]
Low perceived brightness	mean ≤ 42%
Medium perceived brightness	42% < mean ≤ 66%
High perceived brightness	mean > 66%

The classification of users based on the mean value of their selected dimming levels in *study 1* and *study 2* is presented in Figure 24. In *study 1*, the number of users with low, medium, and high perceived brightness preference is seven, three, and four respectively. In *study 2*, four users are classified to have low, four to have medium and two to have a high perceived brightness preference. Four of the users in *study 2* could not be classified since they did not perform any control actions during the study period included in this analysis. It can be seen, that user preferences differ largely for users in the same control zone.

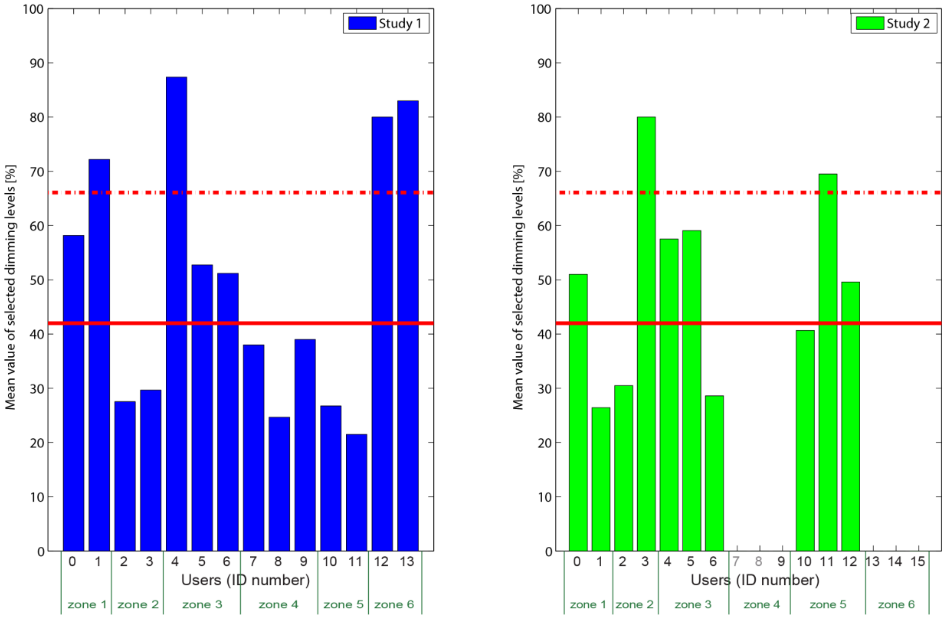


Figure 24. Classification of preference based on mean values of user's selected dimming levels in study 1 (left) and study 2 (right). The solid line discriminates between low and medium perceived brightness preference (42%), the dashed line discriminates between medium and high perceived brightness preference (66%).

3.4.8. Subjective insights

In both studies, the participants assessed the frequency by which they experienced conflict by means of a survey. This evaluation was done at the end of a three weeks period resulting in two evaluations in *study 1* and one in *study* 2 (see Figure 17).

Figure 25 shows the results of the mean frequency of experienced conflict in *study 1* and *study 2*, and Figure 26 shows the mean degree of the experienced conflict. As can be seen, in both studies some participants did report to perceive conflict when controlling lighting. Even though, the degree of the experienced conflict was close to "not at all" for most participants, some participants rated the conflict to be close to "moderate". In interviews, these participants indicated to prefer a different light setting than their neighbouring colleagues. Depending on their dominance, relative to their colleagues, they would either overwrite the lighting to fit their preference, or show conflict avoiding behaviour by not using the light control. Conflict indicated in the survey might not be limited to inter-zone situations. In the interviews of *study 1*, participants of zone 5 and 6 indicated to experience conflicting preferences between the zones.

In the interviews, the participants also shared their self-assessed lighting preference. These lighting preferences differed between users in both studies. The assessments shared in the interviews were generic and consisted of different wording, but could all be translated into three categories: a preference for *low, medium*, or *high* perceived brightness. The results of each user are shown in the overview presented in Table 11. The labels are based on the assessments of the users and do not map to specific illuminance ranges.

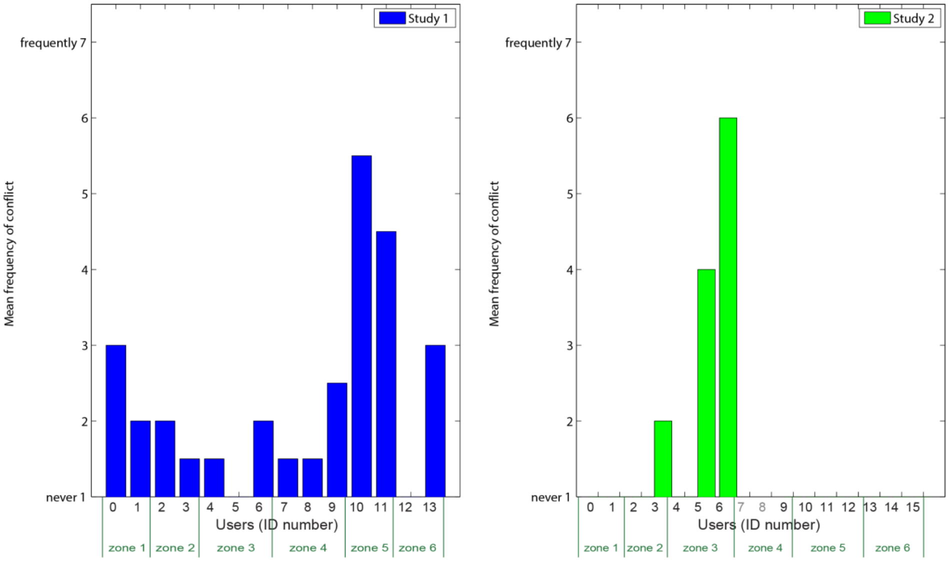


Figure 25. The mean frequency of experienced conflict in study 1 (left) and study 2 (right).

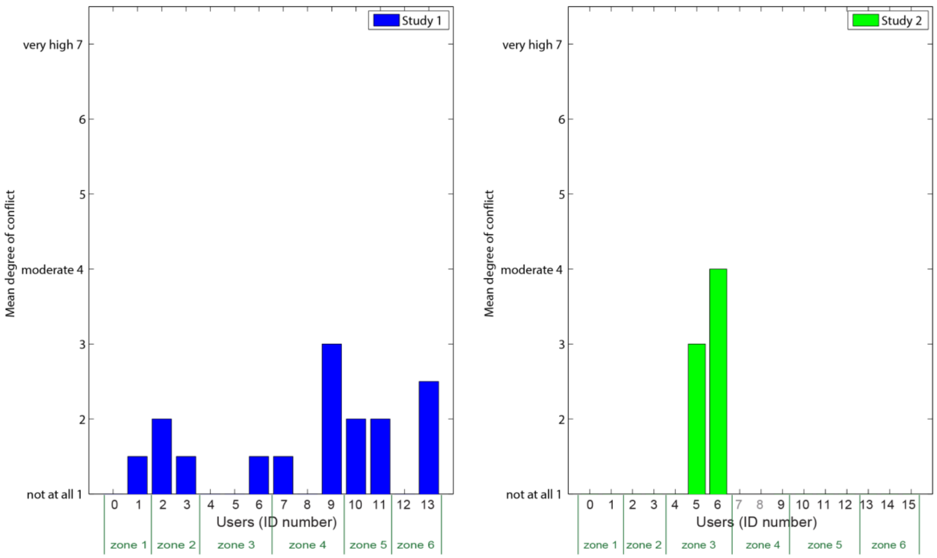


Figure 26. The mean degree of experienced conflict in study 1 (left) and study 2 (right).

3.4.9. Control zone classification

The classification of the control zones can be obtained based on lighting preference profiles of the users who occupied them and the zone luminaire output. By knowing how a control zone is classified, the satisfaction of the individual users within a particular zone can be automatically evaluated and conflict between the users can be predicted. By analysing the different types of user combinations in the control zones and the actions they performed to set their preferred lighting conditions, three cases can be distinguished:

Case 1: All users in a control zone are satisfied, the probability of conflict occurring is low.

Case 2: User(s) in a control zone are dissatisfied, the probability of conflict occurring is high.

Case 3: User(s) satisfaction and the probability of conflict occurring is unknown and therefore, additional input from the user(s) is needed.

Figure 25 presents the flow chart of the control zone classification. If all users in the same control zone are active, their profiles can be derived from the control actions they performed, since they provided enough input. If users have matching preferences, it can be assumed that users are satisfied and that the probability of occurrence of conflict is low which represents *case 1*. If users have opposing preferences, but all of them are tolerant, there will be an overlap between their preferred illuminance levels, which again leads to *case 1*. If more than one user in a control zone is intolerant, meaning that several users are critical regarding the selected illuminance levels, the occurrence of conflict depends on whether these users have matching preferences (*case 1*) or not (*case 2*). If only one user in a control zone is intolerant, and this user is also dominant, meaning that his preferred illuminance level is set in a zone for most of the time, he is assumed to be satisfied. Since other users in a zone are tolerant, the probability of conflict will then be low (*case 1*).

On the other hand, if this user is submissive, he will be dissatisfied with lighting conditions due to his intolerance, leading to a higher probability of conflict occurrence (*case 2*). If inactive users are present in a control zone, deriving their profiles is difficult due to a lack of input from these users. In that case, dominant, inactive users can be identified based on their preference profiles derived from the zone luminaire output data, since there would be a high correlation between their control choices and the prevailing luminaire output. If an inactive user is submissive, there will be insufficient data for a profile derivation and therefore, additional input from the user is needed to obtain an accurate profile of that user (*case 3*).

Based on the analysed data, the summary of the users' profiles as well as the control zone classification is provided in Table 11. Users that did not perform a control action during the studies, are not profiled and left blank in the overview.

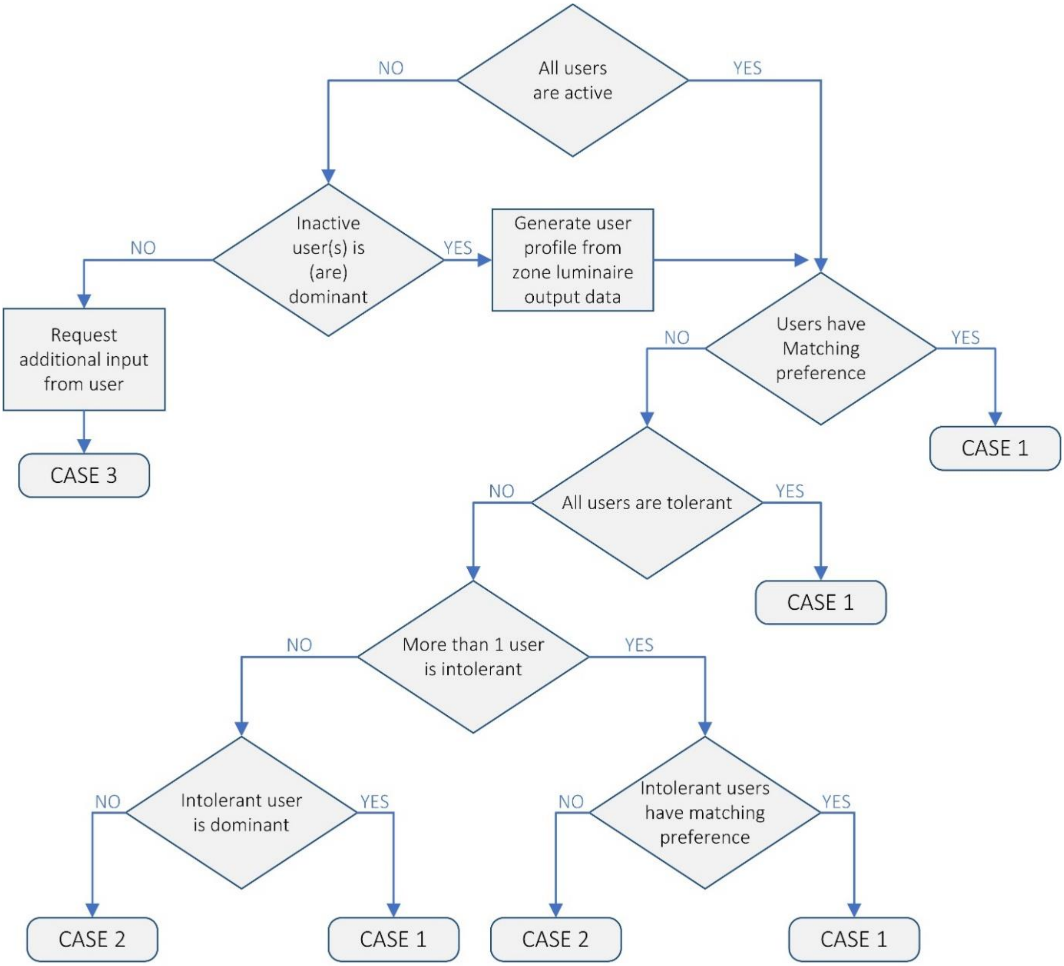


Figure 27. Flowchart of control zone classification.

Table 11. Classification of the users and the control zones.

	Objective measurements						Subjective measurements	
	Zone ID	User ID	Activeness	Tolerance	Dominance	Perceived brightness preference	Zone classification	Perceived brightness preference
Study 1	Zone 1	0	Active	Tolerant	Submissive	Medium	Case 1	Medium
		1	Active	Tolerant	Dominant	High		High
	Zone 2	2	Active	Intolerant	Dominant	Low	Case 1	Low
		3	Active	Tolerant	Submissive	Low		Low
	Zone 3	4	Active	Intolerant	Dominant	High	Case 2	High
		5	Active	Intolerant	Submissive	Medium		High
		6	Active	Tolerant	Submissive	Medium		High
	Zone 4	7	Active	Intolerant	Dominant	Low	Case 1	Low
		8	Active	Tolerant	Submissive	Low		Medium
		9	Active	Intolerant	Submissive	Low		Medium
	Zone 5	10	Active	Intolerant	Dominant	Low	Case 1	Low
		11	Active	Intolerant	Submissive	Low		Low
	Zone 6	12	Active	Tolerant	Submissive	High	Case 1	High
		13	Active	Tolerant	Dominant	High		High
Study 2	Zone 1	0	Inactive	Tolerant [a]	Submissive	Medium [a]	Case 3	Medium
		1	Active	Intolerant	Dominant	Low		Low
	Zone 2	2	Inactive	Intolerant [a]	Submissive	Low [a]	Case 3	Medium
		3	Active	Tolerant	Dominant	High		High
	Zone 3	4	Inactive	Intolerant [a]	Submissive	Medium [a]	Case 3	Medium
		5	Active	Tolerant	Dominant	Medium		High
		6	Active	Intolerant	Submissive	Low		Low
	Zone 4	7	-	-	-	-	Case 3	-
		8	-	-	-	-		-
		9	Inactive	-	Submissive	-		Medium
	Zone 5	10	Active	Tolerant	Dominant	Low	Case 3	Medium
		11	Inactive	Intolerant [a]	Submissive	High [a]		Medium
		12	Active	Intolerant	Dominant	Medium		Medium
	Zone 6	13	Inactive	-	Submissive	-	Case 3	Medium
		14	Inactive	-	Submissive	-		Low
		15	Inactive	-	Submissive	-		High

a) Interpretation of profile based on the available data. Users who did not perform a control action during the studies are not profiled and left blank.

3.4.9.1. Overcoming the limitation of low number of data points

In both studies, the number of data points was generally low due to a number of potential reasons. The user-control conditions in both studies were commissioned with a “memorizing” system behaviour. Starting from a default light setting with a desk illuminance of 300 lx on the first day of both studies, the luminaires within the control group stayed at the previous set dimming level until the next control action was performed. At the end of each day, the last selected dimming level in a specific zone was memorized and restored in that zone upon presence detection the next day. Due to this system behaviour, is it likely that users regarded it as unnecessary to perform further actions after they had set the lighting according to their preference. As also illustrated in Figure 25 and Figure 26, the frequency and degree of conflict was very low for most users. However, some users did experience conflict. The submissive users confirmed in the interviews that they applied conflict avoiding behaviour and felt a hesitation to change lighting even when they were dissatisfied. In *study 2,* four users did not perform any control action during the investigated periods. This could have been due to the users' conflict avoiding behaviour, or due to a broad tolerance of the users. Information about the user's satisfaction with lighting conditions would facilitate the classification of submissive users, since their submissiveness suppresses accurate classification of their preference profiles. Hence, all control zones in *study 2* are classified as *case 3* (see Table 11). When *case 3* is detected, additional input is required to derive the user's lighting preference profile. Figure 28 presents the proposed flowchart to gain this information from the user. The first input is related to the user's satisfaction with lighting conditions, acquired in these studies from the survey results, as explained in Section 3.2.3. If a user is inactive but satisfied, it means that lighting conditions are in accordance with the user's preference, i.e., the probability of occurrence of conflict will be low (*case 1*). In that case, a user's profile can be generated based on the zone luminaire output data, and there is no need for further input. If a user is inactive, but dissatisfied, additional input in the form of preferred lighting is required. This could be done by a push message requesting the user to set the lighting, or by asking the user to evaluate the existing lighting condition. By means of such requests, the profiles of the submissive users can be determined.

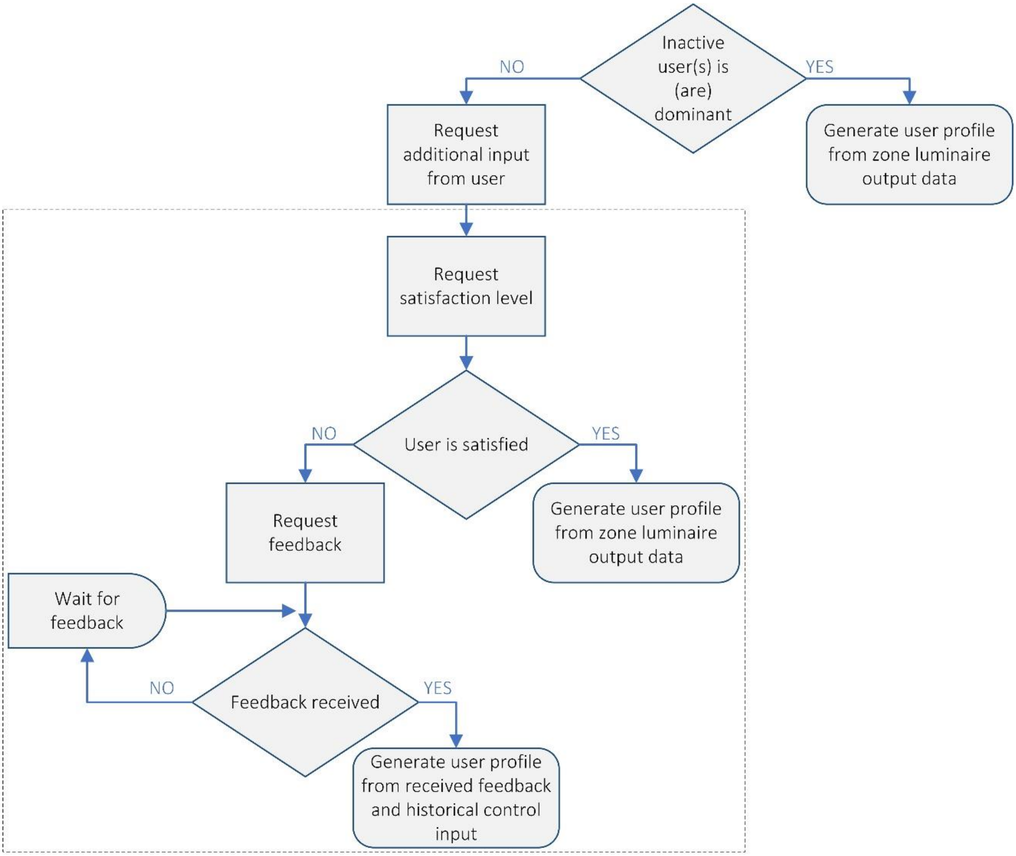


Figure 28. Flowchart of request for additional input from user and derivation of user's lighting preference profile based on user's feedback.

To support the benefits of the proposed approach for deriving the preference profiles of inactive users, subjective survey data regarding users' evaluation of the light quantity on their desk is used. When an inactive user is classified as dominant or is satisfied with lighting conditions, the user's profile can be generated from the zone luminaire output data (see Figure 28). Based on the additional subjective data with regard to user's satisfaction, and when applicable, zone luminaire output, profiles of the inactive users are interpreted and presented as *italic* in Table 12. It is worth noting that only quantitative data of inactive users is evaluated since active users are assumed to provide enough input and that, therefore, their satisfaction and possible conflict within their zones, can be evaluated automatically.

Table 12. Updated classification of the users and the control zones based on satisfaction data.

			Quantitative measurements		Objective measurements				
	Zone ID	User ID	Satisfaction	Perceived light quantity	Activeness	Tolerance	Dominance	Perceived Brightness preference	Zone classify-cation
Study 2	Zone 1	0	Somewhat dissatisfied	A bit too little	Inactive	-	Submissive	Medium [a]	Case 2 [a]
		1	-	-	Active	Intolerant	Dominant	Low	
	Zone 2	2	Satisfied	Just right	Inactive	Tolerant	Submissive	Medium	Case 1
		3	-	-	Active	Tolerant	Dominant	High	
	Zone 3	4	Satisfied	Just right	Inactive	Tolerant	Submissive	Medium	Case 2
		5	-	-	Active	Tolerant	Dominant	Medium	
		6	-	-	Active	Intolerant	Submissive	Low	
	Zone 4	7	-	-	-	-	-	-	Case 1
		8	-	-	-	-	-	-	
		9	Satisfied	Just right	Inactive	Intolerant	Submissive	Low	
	Zone 5	10	-	-	Active	Tolerant	Dominant	Low	Case 1
		11	Satisfied	Just right	Inactive	Intolerant	Submissive	Medium	
		12	-	-	Active	Intolerant	Dominant	Medium	
	Zone 6	13	Satisfied	Just right	Inactive	Intolerant	Submissive	Medium	Case 2 [a]
		14	Somewhat dissatisfied	A bit too much	Inactive	-	Submissive	Low [a]	
		15	Somewhat dissatisfied	A bit too little	Inactive	-	Submissive	High [a]	

a) Interpretation of profiles based on the subjective data on perceived light quantity and satisfaction.

As can be seen, the subjective input in regard to satisfaction with lighting conditions represents valuable information when profiles of inactive users need to be derived. The preferences of users with ID 0, 14, and 15 are interpreted based on the perceived light quantity and their satisfaction. Users with ID 0 and 15 rated their perceived light quantity towards '*too dark*'. In case of zone 1, the predominating dimming level of the zone was in the low brightness range, while in zone 6, it was medium. Therefore, the perceived brightness preferences of the users with ID 0 and 15 are labelled as *medium* and *high*, respectively. Similarly, the user with ID 14, rated the perceived light quantity towards '*too bright*' and his perceived brightness preference is labelled as *low* since the predominating dimming level in this zone was in the medium range. These users represent the clear case of submissiveness and conflict-avoiding behaviour which was confirmed in the interviews. For profile derivation of these users, additional input in terms of preferred lighting is required as presented in Figure 28.

3.5. Conclusions

A first method is proposed for modelling lighting preference profiles of users based on their control behaviour and preference information to offer satisfying lighting to a group of users. The main advantage of the current method is that users' satisfaction and conflict can be predicted purely based on users' control actions and the output of the luminaire, since it cannot be assumed that additional sensorial data (e.g. information about individual presence, daylight contribution, controllable blinds) is available in most of the modern office buildings. The results obtained in the questionnaires and interviews support the validity of the approach, even with limited data. Differences in profiles need to be taken into account when offering lighting conditions in open space environments.

It has been shown that users can be profiled based on their activeness, tolerance, dominance and lighting preferences. By knowing lighting preference profiles of the users and zone classification, the satisfaction of users with lighting conditions can be improved by;

- Predicting the probability of conflict between the users in the same control zone and facilitate in making consensus choices.
- Allocating users to different zones that match their profiles, by having information regarding conflict, thus improving users' satisfaction with lighting conditions.
- Offering lighting conditions that meet the preference profiles of the users. A proposed illuminance level could result from a weighted combination of user profiles and by considering whether users in the same zone are tolerant or intolerant. A tolerant user can be satisfied with a broad range of illuminance levels and therefore, the weighting needs to be done by shifting a proposed illuminance level towards a preference of an intolerant user.
- Triggering submissive, inactive users to express their preference. A submissive user's choices are not correlated with the prevailing luminaire output in his zone. This situation might lead to increased discomfort of this particular user. In that case, additional user input is required to derive the lighting preference profile as accurately as possible.

A semi-automatic system which proposes lighting conditions automatically by using lighting preference profiles can support users in finding consensus in addition to the benefits of manual personal control. In the presented methodology, it has been assumed that lighting preference of a user can be derived based on user's control actions only. Further elaboration on environmental factors influencing user's preference is recommended for future work. In that case, the prediction of users' control actions in terms of offering satisfactory lighting conditions can be performed based on the contextual data collected in the office. Furthermore, access to lighting preference profiles of office users can improve design decision making as well as help facility managers to optimize their building operation strategies.

Chapter 4

4. Influence of wall brightness on preferred task illuminance

This chapter is based on the following publication:

S. Chraibi, L. Crommentuijn, E.J. van Loenen, A.L.P. Rosemann, Influence of wall luminance and uniformity on preferred task illuminance, Build. Environ. 117 (2017) 24-35.

Literature suggests an influence of the luminance from non-horizontal surfaces in our visual field on our visual and psychological assessments of an office space. These assessments are believed to directly relate to our expressed preferred task illuminances.

This Chapter describes an evaluation in a mock-up office, wherein wall conditions with a non-uniform and a more uniform light distribution of three different average luminance levels have been evaluated regarding their effect on users' preferred task illuminance. Each condition was evaluated starting from three different initial desk illuminances.

For all test conditions, a wall with a non-uniformly distributed average luminance of 200 cd/m^2 led to significantly lower selected desk illuminances than a uniformly lit wall with the same average luminance level. In all cases, preferred task illuminances were significantly lower when offered a starting level for dimming of 300 lx. The range of preferred illuminance levels between subjects was also found to be smaller for dimming with the starting level of 300 lx at desk level.

The study suggests that when providing users with personal control they will control the total perceived brightness in their visual field, even though they are only directly affecting their task illuminance level. Triggering the selection of lower preferred illuminance levels by using a personal control starting level of 300 lx, will reduce the energy required for lighting. The smaller range of preferred illuminance levels between subjects at the starting level of 300 lx could reduce the risk of lighting preference related conflict between people.

4.1. Introduction

With the changing character of office work, most of our tasks today include non-horizontal surfaces in the visual field. Literature indicates relations between the brightness of these non-horizontal surfaces and the users' visual and psychological assessments of the space. Increasing wall luminance has led to a more stimulating room (van Ooyen et al., 1987), increased assessment of brightness acceptability and pleasantness (Carter et al., 1994a), and high brightness perceptions have been linked to improved assessments of comfort and spaciousness (Manav, 2007). Besides the improved assessments, increased wall luminance has also been linked to lower preferred desktop illuminances (van Ooyen et al., 1987), offering the potential to support energy efficiency. Reinforced by standards certifying and monitoring the performance of building features that impact wellbeing (International WELL Building Institute, 2016), users' feeling of happiness, health, and comfort becomes equally relevant.

Personal control is recognized as a means to enhance user satisfaction (Moore, Carter, & Slater, 2004; Newsham & Veitch, 2001; Newsham, Veitch, Arsenault, & Duval, 2004; Veitch, Newsham, Boyce, & Jones, 2008) and energy efficiency (Boyce et al., 2000, 2006b, 2006a; Williams et al., 2012). When applied in shared open office spaces, personal control becomes consensus control. In the field study described in Chapter 2, it was shown that providing users with consensus control over a group of luminaires resulted in lower energy usage and improved satisfaction with light quality and quantity, compared to a situation without control (Chraibi et al., 2016). Even though consensus control did improve satisfaction compared to a no-control situation, some users did experience conflicting preferences with their neighbours regarding preferred illuminances. A challenge remains, in designing office lighting that limits the risk of conflict between people due to differences in lighting preference, while maintaining the energy saving benefits.

4.1.1. Background

When offered control, people are given the ability to alter the illuminance on their desk. Besides the benefits of lighting within the preference of users (Newsham, Veitch, et al., 2004b), Sadeghi et al. (2016) recently reported a relation between occupant perception of control and the acceptability of a wider range of visual conditions. This increases in relevance when dealing with multiple users in one open office space. However, the experiments of Sadeghi et al. were conducted in private offices. In 2013 and 2014, field studies were performed evaluating personal control in an open office (Chraibi et al., 2016; Lashina et al., 2019). In the interviews the participants shared their self-assessed lighting preference, which could be generalized in a *bright*, *medium*, or *dark* preference category (Despenic et al., 2017). This self-classification could be based on the users' preference for task illuminance levels for the visual task but could also be their preference regarding the office appearance. Fotios (2011) also points out the importance of office appearance, stating that even though it has been shown that tasks on self-luminous displays could be carried out on lower illuminance levels, this is not done, as people like a bright and visually interesting environment. If perception of brightness could be maintained at a lower desk illuminance level, energy consumption could be reduced.

Due to a strong tendency of subjects to assess the brightness of all areas similarly, Moore et al. (2003a) stated that occupants view the luminous environment as a whole. This suggests that control may have the potential to influence opinions of areas other than those directly controlled. Moore did not find any relationships between the users liking the environment and an increasing or decreasing assessment of brightness in the reported study. In a study performed by Manav (2007), a strong increase in the desk illuminance did lead to improved user assessments of comfort and spaciousness. When increasing the desk illuminance from 500 lx to 2000 lx, the users' brightness evaluation of the wall opposite the user also increased, which was evaluated positively. Changing the correlated colour temperature of the lighting did not affect the perceived brightness in this study.

It was already in 1987 that Van Ooyen et al. (1987) showed that the preferred work plane luminance depends on the wall luminance. With increasing wall luminance, a lower desktop luminance was preferred, and vice versa. They stated that the wall luminance contributed most to the way the room was experienced, where increasing the wall luminance lead to a more stimulating room. Carter et al. (1994a) suggested an influence of wall luminance on the user's perception of horizontal illuminance through increased assessment of acceptability of brightness and pleasantness when increasing the wall luminance. Berrutto et al. (1997) showed with their first phase experiments in 1994, that participants preferred wall luminance levels to be minimized behind the monitor when performing a PC task. However, the task did consist of white characters displayed on a dark background, which is not common in current regular office tasks. In the second phase of the study, in 1997, they used a standard Word document task with black characters on a white background and reported that subjects preferred a screen immediate surround luminance inferior or equal to the screen background luminance (Berrutto et al., 1997). In the same study, they also showed that subjects who set low horizontal illuminance levels (respectively high illuminance levels) tended to also set a low luminance on walls (respectively high wall luminance). They concluded that, regardless of the task performed, the wall luminance was shown to have a significant effect on users' satisfaction and appeared to deserve more attention.

In a study performed by Durak and colleagues (2007), different lighting arrangements were evaluated on their impact on impressions of the space. The arrangement including illumination of walls by wall washing scored the highest regarding the evaluation of spaciousness and visual order. Islam et al. (2015) showed in their acceptance studies, that users' preferred light conditions were influenced by the task illuminance, which was found to relate to the spatial brightness. The term spatial brightness relates to the perceived brightness of a space (Duff, Kelly, & Cuttle, 2017). The users preferred the conditions under which they found the lighting environment to look brighter and more spacious (Islam et al., 2015). In a laboratory study performed by de Vries et al. (2015) with 37 participants, three wall luminance conditions were assessed with average luminance levels of 11, 36, and 73 cd/m^2 respectively. Increasing wall luminance levels lead to increasing room appraisal by the subjects, regarding attractiveness as well as illumination. The higher wall luminance made the overall office appear more spacious and more attractive.

In a study by Sheedy et al. (2005) the effects of the luminance surrounding of a computer monitor were evaluated. When performing tasks on a monitor with a luminance of 91 cd/m^2, optimal performance by the users occurred when the surround luminance was 50 cd/m^2 or higher for the younger group of subjects (23-39 years) and 91 cd/m^2 or higher for the older group (47-63 years). The preferred surround luminance was 87 cd/m^2 for the younger and 62 cd/m^2 for the older group, both below the luminance of the screen. In the study performed by Yang et al. (2014) the preferred background luminance intensities were found to be linearly correlated with screen luminance intensities. However, in this study the computer screen was positioned directly against a wall, and only the direct surround of the screen was taken into consideration.

In the latter study of Sheedy, the wall was uniformly lit using a projection. In a study performed by Tiller and Veitch (1995) rooms with a non-uniform luminance distribution appeared brighter for the subjects than the uniform variants. The non-uniform rooms required less work plane illuminance to reach a brightness impression equivalent to the rooms with a uniform luminance distribution. Sullivan and Donn (2016) reported in their literature review that the majority of studies suggest that more uniform lighting appears brighter than less uniform lighting. In the pilot study presented in the same paper, Sullivan and Donn showed that less uniform spaces were evaluated to appear brighter, similar to the results of Tiller and Veitch. Disagreement in literature about the direction of this effect raises the possibility that the relationship between uniformity and spatial brightness may be more complicated than this. 'Brightness' (perceived luminance) and 'visual interest' (variation in luminance) are stated by Moore et al. (2004) as two features associated with visually preferred environments. There is however a limit. Newsham et al. (2004) showed in an earlier study that people want spaces that are somewhat uniform, but not monotonous. Veitch and Newsham (2000b) state that a difference might exist between the preferred luminous conditions and the interestingness of a space, which increases with a wider variation of luminance.

Most studies do suggest walls to be particularly important to affect the apparent brightness. This may however also be due to their dominance in the observed visual field, or their lead role in performed studies. Sullivan and Donn (2016) reported that it is 'plausible' that the walls are of particular importance to the brightness impression of a space, but that literature does not provide sufficient evidence to support such claims.

In an open office, the walls enclosing the office are shared by the users of the office as part of their visual field. Based on previous studies, the walls are believed to influence the brightness perception of the office space, and with that influencing the preferred task illuminance of users, as expressed by personal control. In this Chapter the results of a laboratory study are described in which the effects of the wall luminance and wall uniformity on the preferred task illuminance are evaluated.

4.1.2. Hypotheses

Based on previous studies, it is believed that when providing office workers with task lighting control, users do not only select a preferred task illuminance to meet personal requirements for their visual task. They furthermore see in the personal control a means to set a visually preferred lighting environment. This includes the task lighting but also the surrounding luminance distribution. Consequently, it is hypothesized that the wall luminance in the visual field of the user will influence the user's preferred task lighting.

High wall luminance levels are believed to lead to lower preferred task illuminances, due to a higher brightness perception. High wall luminance levels are believed to reduce the difference in preferred task illuminance between occupants.

Depending on the luminaires used, walls can be illuminated with a different level of uniformity. As shown by Tiller and Veitch (1995) and Sullivan and Donn (2016), a non-uniform wall luminance distribution is expected to increase the brightness perception compared to a more uniform illuminated wall. Due to this higher brightness impression, a non-uniform wall luminance distribution is believed to lead to lower preferred task illuminances. A non-uniform wall luminance distribution is believed to also reduce the difference in preferred task illuminance between occupants.

4.2. Methodology

In a simulated work environment, an experiment has been carried out to evaluate the stated hypotheses. A lighting system was installed to create different lighting conditions. Participants were invited to experience these conditions and make adjustments expressing their preferred lighting.

4.2.1. Testbed

The user study was conducted in a laboratory in the Netherlands, where a full-scale mock-up office of 7.2 x 7.2 x 2.8 m was built. The participant's visual field included multiple desks, the ceiling and a wall, simulating a situation in an actual open office space. Figure 29 shows an impression of the space. Four desks were equipped with a mouse, a keyboard and a Philips 24" Brilliance LCD monitor, set to an identical screen luminance with an average of 100 cd/m^2. The participant's desk (desk 4) also had a user interface to select the desired task illuminance. The fifth desk (desk 5) was equipped with two laptops and a control panel for the researcher to switch between light conditions. Screens in front of the windows blocked the daylight in order to exclude the impact of exterior light variations on the experiments.

The electric lighting system consisted of twelve dimmable recessed ceiling Philips PowerBalance LED Luminaires (600 x 600 mm, 4000 K, $R_a > 80$, UGR<16, 34S, 3400 lm) and ten Philips StyliD Compact power LED spots (4000 K, $R_a > 80$, SLED17, 2000 lm). The lighting system was divided in five luminaire control groups, as shown in Figure 30, to obtain the desired light settings during the experiment. Three luminaire groups illuminated the walls; six recessed luminaires (group 1) and five spots (group 2) illuminated the 'test wall' in front of the user, and five spots illuminated the wall behind the user (group 3), to avoid an uncomfortable dark background. Two luminaire groups illuminated the desks in the office space; the 'control group' consisted of 2 recessed luminaires controllable by the participant (group 4), and four recessed luminaires were commissioned to illuminate the other desks at a constant level during the test (group 5). The 'control group' consisted of two luminaires to simulate shared control in open office environments (Chraibi et al., 2016; Moore et al., 2004), and allow for a dimming range from approximately 300 lx to 700 lx average desk illuminance. Figure 31 shows the luminous intensity distribution of the 'control group' luminaires.

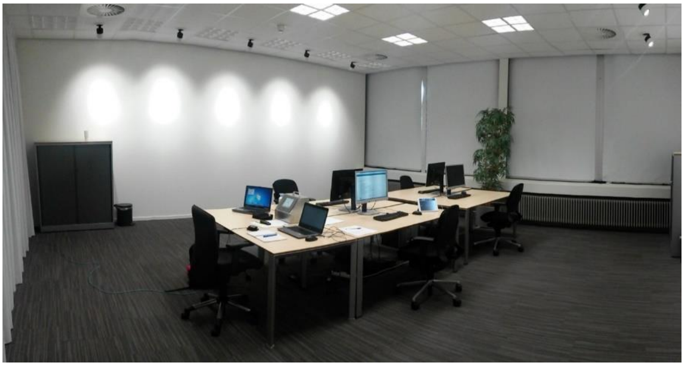


Figure 29. Impression simulated work environment.

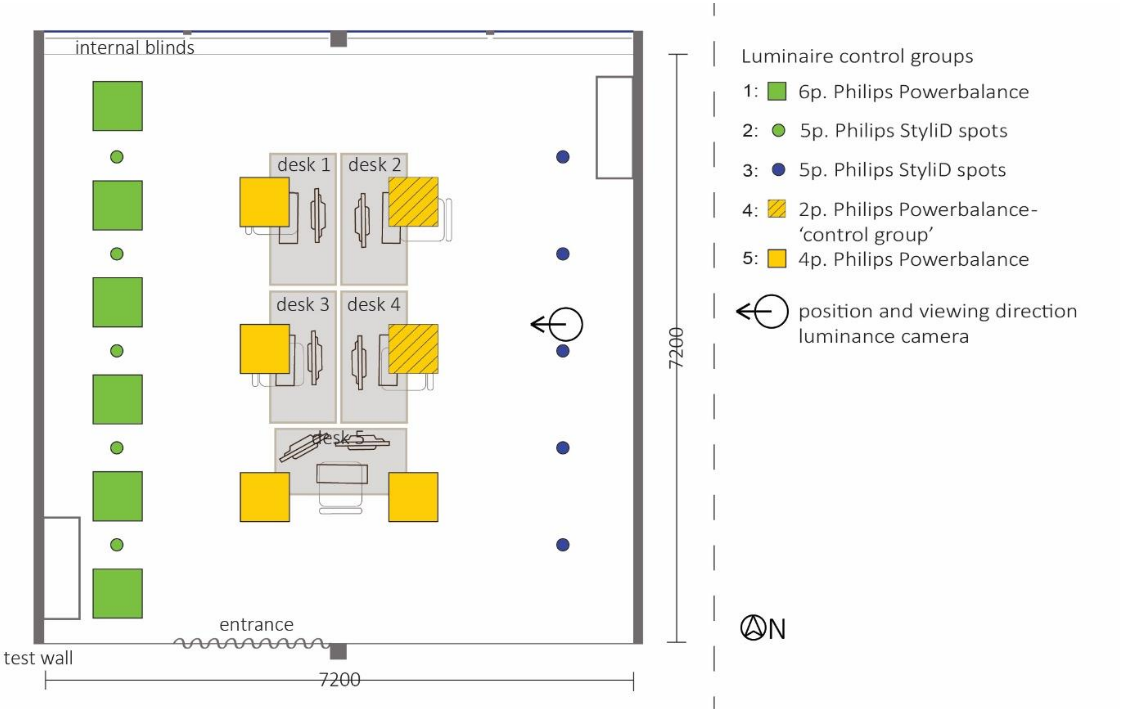


Figure 30. Floorplan simulated work environment.

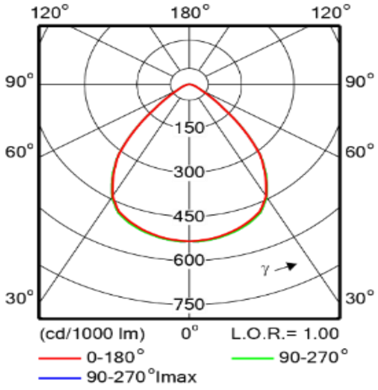


Figure 31. Photometric diagram 'control group' luminaires (Philips PowerBalance).

4.2.2. Participants

For the experiment the inclusion criteria used, encompassed participants to be between 20-30 years old to eliminate the effects of age on the perception of light. Participants should also not work in the field of lighting application or perception and not visual disabilities that are not compensated by lenses or glasses.

Recruitment was done using flyers with a call for volunteers, distributed at both the technology as well as the university campus of the city.

A total of N=54 subjects participated in the study. N=30 were male, and N=24 were female, with an age varying from 18-29 years. Participants were rewarded for their participation in the study with a gift voucher.

4.2.3. Study design

The experiment was conducted in August and September of 2015, on weekdays between 9 am and 6 pm. Each experimental session included one participant at a time with a total duration of 1.5 hours. Each test day had four experimental time slots.

Participants were seated at desk 4 and started with unconscious adaptation to the baseline light setting, commissioned at an average horizontal desk illuminance of 500 lx. Both the 'test wall' and the wall behind the user were non-uniformly lit with a first luminance condition of the 'test wall' set in accordance with the participant's experimental sequence. During this adaption time (approximately 10 minutes), the researcher explained the experimental procedure, and the participant filled in an online survey on the PC. The survey included demographic questions and a question asking people to assess their general distraction level on a 7-point Likert scale from very slow to very fast.

During the test, the participants were asked to perform a reading task provided on the PC monitor. The reading task consisted of a page with randomly picked "did-you-know" facts. The simple reading task was selected to avoid deep visual focus on the PC monitor and enable observation of the office environment. Every 60 seconds the participant was interrupted by the researcher to set a preferred dimming level of the ceiling mounted luminaire above his desk, using the provided user interface. When the desired desk illuminance was obtained, the participant pressed the save button in the top bar of the user interface (Figure 32), to log the preferred level. By pressing the buttons 1 and 2, the start point (of the controllable ceiling luminaire) was changed to minimum or maximum, for the user to again set his preference for this wall brightness light condition. After setting and storing the preferred illuminance for all three start points (ca. 300 – 500 – 700 lx desk illuminance), the researcher switched the system to the next light condition. The participants could move to the next reading page on the PC, until interrupted for a next preference selection. This was repeated until all conditions were evaluated twice. The interaction with the slider directly dimmed luminaire control group 4 up or down (Figure 30), influencing the task illuminance of the participant based on the selected dimming levels in each condition. The final set preferred illuminance was logged for each condition. At the end of the experiment, in a conversation between the researcher and the participant additional experiences which the participant wanted to share were captured.

4.2.4. User interface

To avoid that the user interface had any influence on the selected illuminance, the slider was designed to not have an anchor point nor a reference to the last selected level (Figure 32). Previous studies (Uttley et al., 2013) have shown that people are not consistent in the choices they make when selecting a task illuminance. The range of the provided control interface as well as the starting position when offered control were shown by Fotios et al. (2012) to have an influence on the selected illuminances. Additionally, participants might self-classify their lighting preference, as "I like bright light", or "I prefer dimmed lighting", which could influence them to select their preference on a similar end of the scale (Chraibi et al., 2016).

In this study, the interface was offered on a tablet, placed vertically on the desk. It was decided not to present the interface on the PC monitor, to trigger people to look away from their monitor and observe the office space. To avoid reflections of the luminaires on the interface screen, but allow for easy interaction, the user interface was positioned under an angle, as shown in Figure 32. The simplicity of the interface interaction enabled the participants to maintain their viewing direction when using the interface. Participants received instructions on the use of the interface during the introduction at the start of the experiment. To avoid centring bias (Fotios et al., 2012), the user interface design did not provide a reference to the centre of the range. Sliding from the middle to the right dimmed the lighting up and sliding from the middle to the left dimmed it down. Major sliding movements from the middle to the end translated to changing the dimming level by a step of 6% of the maximum luminaire output. Minor sliding movements led to a dimming step of 3%. Multiple sliding movements, back and forth from the centre, could be made by the participants, until the preferred level was set.

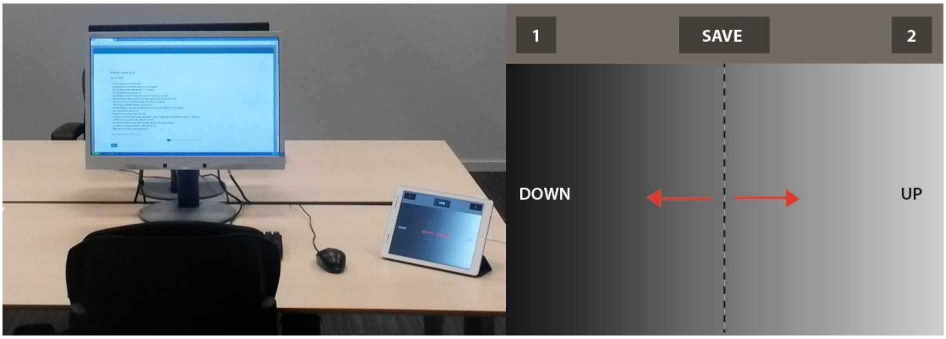
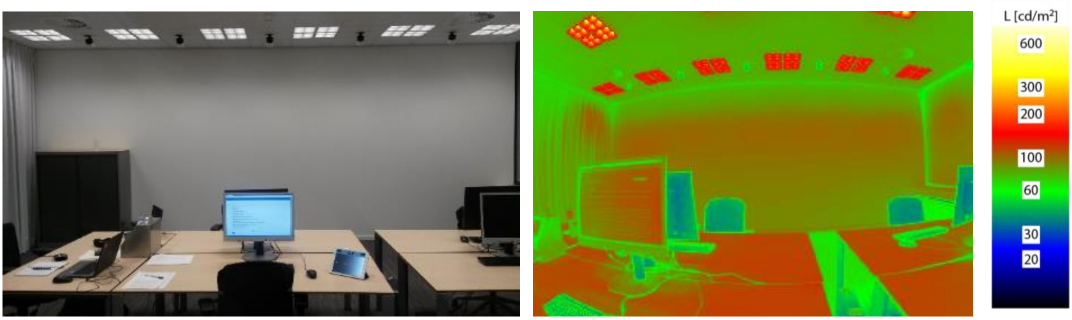


Figure 32. User interface position on the desk – layout of the slider for light control. After a user set his preference, the save button was pressed. The numbers 1 and 2 were pressed after instructions from the researcher to switch to a minimum or maximum start point of the luminaire dimming level.

4.2.5. Light conditions

To evaluate the influence of wall luminance and uniformity on the preferred task lighting, the participants were asked during the test to select their preferred illuminance for different light conditions. These conditions consisted of three different average wall luminance levels, offered in a non-uniform distribution as well as a more uniform distribution. The uniformity describes how evenly the light is spread on a surface, i.e. in this study the uniformity of the wall luminance. To create wall conditions with a uniform luminance distribution, a combination of five recessed luminaires and five spots was used (group 1 + 2, Figure 30). The light conditions were commissioned to obtain as much uniformity as possible with the lighting installation, for three different luminance levels. To achieve non-uniform wall luminance distributions, only the five wall spots directed at the wall were used (group 1, Figure 30), for three different luminance levels. Table 13 presents the luminance characteristics of the six different conditions. (Note that the absolute luminance values can be influenced by the resolution of the camera.) The non-uniform conditions are labelled N50, N100, and N200, with the number referring to an approximation of the average wall luminance level. The uniform conditions are labelled U50, U100, and U200, with again the number referring to the average wall luminance level. The conditions were commissioned using the average wall luminance, measured with a luminance camera (LMK5 Color with software package Technoteam LMK LabSoft Standard Color v12.7.23). The lighting installation was designed to meet the proposed average wall luminance as well as the default desk illuminance of 500 lx. Figure 33 and Figure 34 show impressions and luminance distribution images of the different conditions, with the level of uniformity U_L (= L_{min} / L_{avg}) of the 'test wall'.



a. Uniform, $L_{wall;avg}$=50 cd/m^2, U_L=0.69

b. Uniform, $L_{wall;avg}$=100 cd/m^2, U_L=0.48

c. Uniform, $L_{wall;avg}$=200 cd/m^2, U_L=0.43

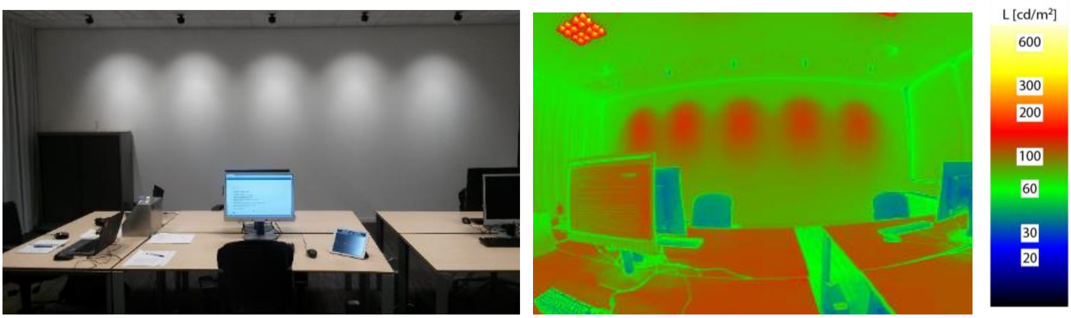
Figure 33. Pictures and luminance distribution images of the uniform wall conditions.

Table 13. Properties of the different wall conditions.

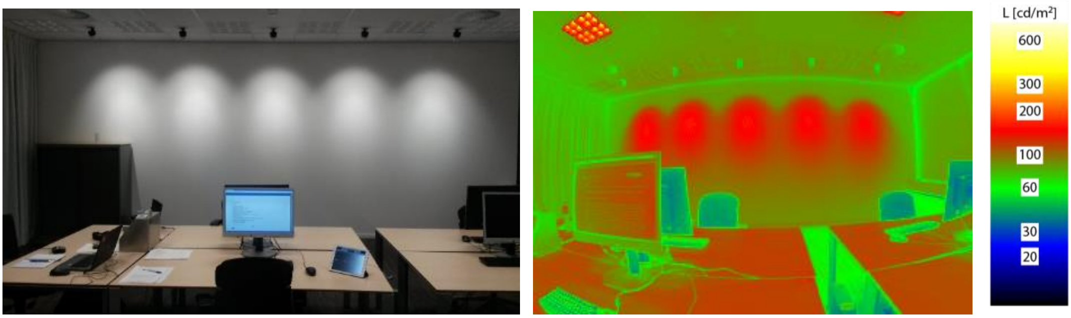
Non-uniform	Luminance in cd/m^2				U_L
	Min	Max	Range	Avg	
N50	23	111	88	52	0.44
N100	28	217	189	104	0.27
N200	48	600	552	253	0.19

Uniform	Luminance in cd/m^2				U_L
	Min	Max	Range	Avg	
U50	36	67	31	53	0.69
U100	50	167	117	105	0.48
U200	94	362	268	217	0.43

U_L (=L_{min} / L_{avg})



a. Non-uniform, $L_{wall;avg}$=50 cd/m^2, U_L=0.44



b. Non-uniform, $L_{wall;avg}$=100 cd/m^2, U_L=0.27

c. Non-uniform, $L_{wall;avg}$=200 cd/m^2, U_L=0.19

Figure 34. Pictures and luminance distribution images of the non-uniform wall conditions.

For each wall setting, three different start points are used from which the participants dimmed up or down to select their light preference. The study of Uttley et al. (2013) demonstrated that besides the influence of the offered range on the selection of preferred illuminances, the start point has an influence as well. They showed that when offering a low start position, illuminance levels selected were lower than when offering a high start position, as also in an earlier evaluation (Fotios & Cheal, 2010). Results of the ratings of satisfaction with the illuminance did not suggest an effect of the different ranges or start positions offered, despite the significant difference in illuminances (Uttley et al., 2013).

The three start positions used in the current experiment were: the default of 500 lx at the desk as by standards recommended (NEN-EN 12464-1, 2011); a maximum setting of 700 lx by which 90-99% of people are expected to achieve their preferred illuminance (Boyce et al., 2006b); and the minimal luminaire output of the control group, leading to a desk illuminance around 300 lx. Table 14 shows the different conditions, and the corresponding average horizontal task (desk) illuminance of desk 4, being the participant's workplace. In each setting, users could select their preferred illuminance in the range corresponding to the presented values from minimum to maximum. The luminaires above the other desks were commissioned to deliver a desk illuminance of 500 lx on average in the default start position and were kept constant for all three start positions of that wall setting.

Table 14. Test conditions with the desk illuminance for the different start positions.

Wall setting	Distribution	Desk illuminance in lx at desk 4, at start point:		
		min	default	max
N50	Non-uniform	308	535	722
U50	Uniform	311	549	725
N100	Non-uniform	312	525	725
U100	Uniform	321	560	735
N200	Non-uniform	335	528	749
U200	Uniform	294	471	707

Each participant was asked to set the preferred task lighting in a first and second trial for all wall lighting conditions, to evaluate the consistency of the users. An overview of the average horizontal illuminance at desk 4, measured at different dimming levels of the controllable luminaires, is shown in Table B.1 Appendix B. The conditions were presented to the participants in different sequences to avoid an order effect. The six different sequences used during the study are presented in Table B.2 Appendix B. Each condition was first evaluated from the default dimming start position, followed by the minimum and the maximum start position, before continuing to the next condition. For sequence 1, this meant $N50_{def}$, $N50_{min}$, and $N50_{max}$, followed by $U50_{def}$, $U50_{min}$, $U50_{max,}$ and so on.

4.2.6. Analyses

The preferred illuminance was selected by the participants on a continuous scale. Given the large sample size and the normal distribution of the data, differences between conditions were analysed using a paired samples t-test and a repeated measures analysis of variance. Effect size calculations are done using eta squared ($\eta^2 = t^2/(t^2 + N - 1)$). Interpretation of the eta squared values is done following guidelines of Cohen (1988) (from Field, 2009; Pallant, 2002), with 0.01=small effect, 0.06=moderate effect, and 0.14=large effect. A within-subject repeated measures analysis of variance was used to analyse an effect of self-rated sensitivity to distractions on preferred desk illuminance. A one-way between-subjects analysis was used to assess effects of demographic characteristics or independent between-groups variables on preferred desk illuminances. For the significance tests, a significance of p=0.05 was used. Analyses were performed using IBM SPSS Statistics version 23.

Data of the informal interviews at the end of each experimental session was logged. This data was analysed by identifying concepts based on key phrases. These concepts were clustered in categories.

4.3. Results

4.3.1. Control variables

A repeated measures analysis of variance test with two within-subject factors showed no significant interaction effect between start point and trial for the different wall conditions (p>0.05), and no significant main effect for trial in which the preferred illuminance was selected in each condition (p>0.05). In further analyses the average value of the preferred illuminance selected by each participant in the first and second trial is used. The start point did show a significant main effect on the illuminances selected by the users in all conditions (p=0.000). The start points will not be combined, and will be analysed separately for all conditions, resulting in 18 different conditions.

As stated in Section 4.2, participants evaluated the conditions in one of six different sequences, and during one of four timeslots. A one-way between groups analysis showed no significant effect of the experienced sequence on selected illuminance (p>0.05) nor of participation timeslot (p>0.05). In further analyses, no distinction in the population will be made based on sequence or timeslot.

By means of a one-way between groups analysis, the demographic characteristics of the subjects are evaluated regarding their effect on preferred illuminances. No significant effect was found for subjects' age, gender, visual corrections, ethnic origin, level of education, or type of work the subjects perform in their daily job.

4.3.2. Wall luminance conditions

Results of the preferred illuminances of the users are presented in Figure 35, with from left to right the conditions with an average wall luminance of respectively 50 cd/m^2, 100 cd/m^2, and 200 cd/m^2. Pairs of a non-uniform (N) and more uniform (U) wall condition with a similar average wall luminance and start point are presented alongside each other. The boxplots show the spread of preferred desk illuminance levels in lx.

Uniformity

To analyse the effect of uniformity, pairs were created between the non-uniform (N) and more uniform (U) wall conditions with a similar average wall luminance and start point. A paired samples t-test was performed for each pair. The non-uniform 200 cd/m^2 (N200) conditions showed a significant lower preferred desk illuminance than the uniform 200 cd/m^2 conditions (U200), for all three start points (Table 15), with a moderate effect size for the default start point and a large effect size for the minimum and maximum start point. No effect of uniformity on selected illuminances was found for the conditions with a wall luminance of 50 cd/m^2 and 100 cd/m^2 ($p>0.05$). Detailed results of all paired samples are presented in Table B.3 Appendix B. In further analyses, an average preferred illuminance of the uniform and non-uniform conditions was used for the 50 cd/m^2 and 100 cd/m^2 wall luminance conditions. These are labelled as conditions X50 and X100 respectively.

Table 15. Results paired samples test on wall uniformity.

	Sig. (2-tailed) [a]	Effect size [b]	Mean difference in lx
$N200_{min}$ - $U200_{min}$	0.000	0.58	-47
$N200_{def}$ - $U200_{def}$	0.011	0.12	-22
$N200_{max}$ - $U200_{max}$	0.000	0.44	-43

a) paired samples t-test; b) eta squared: $\eta^2 = t^2/(t^2+N-1)$

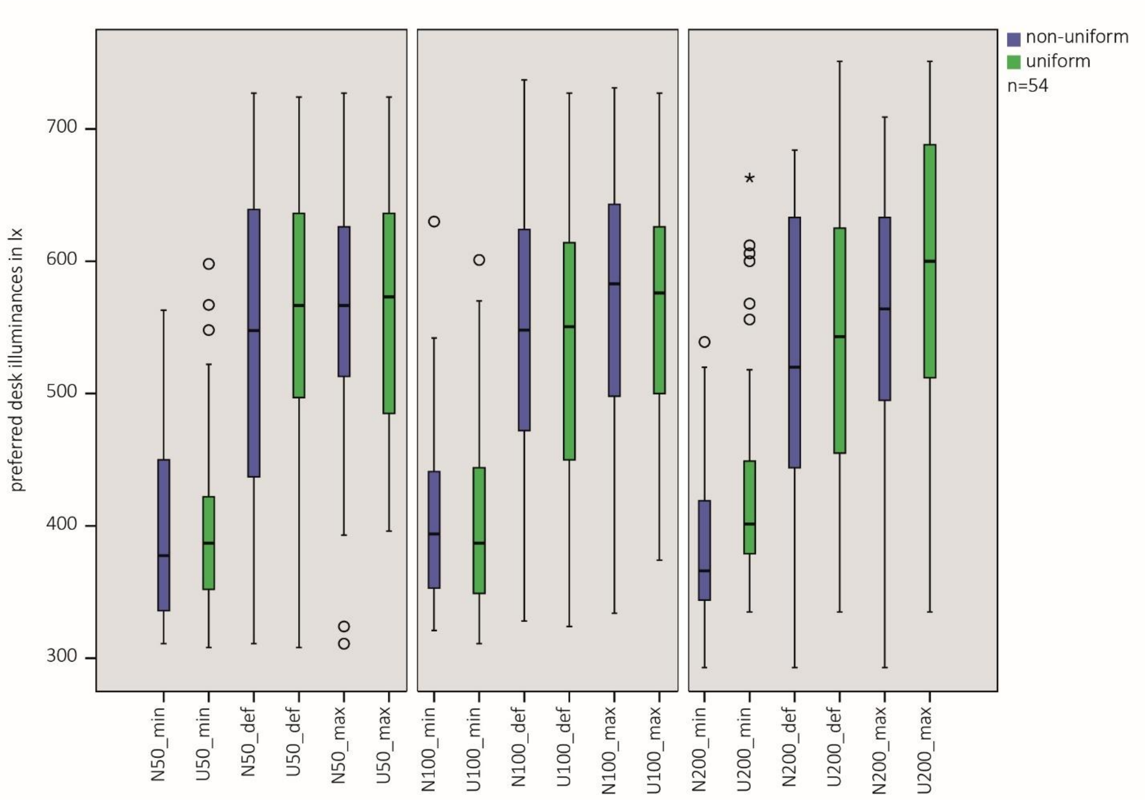


Figure 35. Boxplots of preferred desk illuminance for each wall condition.

Luminance

For the analyses, conditions with a similar start point and a different average wall luminance were paired. The preferred illuminances of the users were compared by using the paired samples t-test. Preferred desk illuminances did not differ significantly between the X50 to the X100 conditions for any of the three start points ($p>0.05$). Preferred desk illuminances did differ significantly for most start points when comparing the X50 as well as the X100 conditions to the uniform and non-uniform 200 cd/m^2 conditions, with a moderate to large effect. Detailed results of all paired samples are presented in Table B.4 Appendix B. Table 16 shows the results of the paired samples with a significant effect. Compared to the X50 and X100 conditions, the selected illuminances are higher in almost all uniform 200 cd/m^2 conditions and lower in the non-uniform 200 cd/m^2 condition, as shown by the mean difference in lx presented in Table 16. Detailed results of all paired samples are presented in Table B.4 Appendix B.

Table 16. Results paired samples test on average wall luminance.

	Sig. (2-tailed) [a]	Effect size [b]	Mean difference in lx
$X50_{min}$ - $U200_{min}$	0.000	0.42	-37
$X50_{max}$ - $U200_{max}$	0.000	0.23	-33
$X100_{min}$ - $U200_{min}$	0.000	0.25	-29
$X100_{max}$ - $U200_{max}$	0.000	0.24	-31
$X50_{min}$ - $N200_{min}$	0.025	0.09	10
$X50_{def}$ - $N200_{def}$	0.002	0.18	31
$X100_{min}$ - $N200_{min}$	0.001	0.18	18

a) paired samples t-test; b) eta squared: $\eta^2 = t^2/(t^2+N-1)$

Preference spread

The spread of the users' selected illuminances in each condition, as displayed by the boxplots in Figure 35, did not suggest an effect of uniformity or wall luminance on the differences between people's preference. The boxplots did indicate an effect of start point on the spread of preferences, with a smaller spread for the minimal start point. This smaller spread is quantified in Table 17 by the interquartile ranges (IQR), with smaller interquartile ranges for the minimal start points of all conditions (IQR) than for the default and maximum start points of all conditions. Table 17 presents the descriptive statistics of each condition, sorted by increasing interquartile range.

Table 17. Descriptive statistics of the selected illuminances in lx of 18 conditions.

	avg	min	max	range	IQR ↓
$U200_{min}$	432	335	663	328	70
$U50_{min}$	397	308	598	290	75
$N200_{min}$	385	293	539	246	77
$N100_{min}$	402	321	630	309	93
$U100_{min}$	403	311	601	290	97
$N50_{min}$	393	311	563	252	116
$N50_{max}$	558	311	727	416	120
$U100_{max}$	566	374	727	353	129
$N200_{max}$	551	293	709	416	138
$U50_{def}$	562	308	724	416	142
$N100_{max}$	562	334	731	397	150
$U50_{max}$	564	396	724	328	154
$N100_{def}$	545	328	737	409	155
$U100_{def}$	534	324	727	403	169
$U200_{def}$	543	335	751	416	172
$U200_{max}$	595	335	751	416	178
$N200_{def}$	521	293	684	391	194
$N50_{def}$	543	311	727	416	205

N=54 , IQR – inter quartile range; the spread presented by the difference between the first and third quartile

4.3.3. Self-assessed level of distraction

Participants were divided in five groups, based on their self-assessed sensitivity to distractions, expressed in the survey. The five groups represent people that are generally distracted slowly (n=5), somewhat slowly (n=0), neutral (n=15), somewhat fast (n=27), and fast (n=7). Figure 36 shows the mean preferred desk illuminance of each condition for the different distraction categories. The fast-distracted people had the lowest mean preferred desk illuminances, and the slow distracted people the highest. A repeated measures analysis confirmed an effect for the self-assessed distraction sensitivity on the preferred illuminances with a large effect size(F=5.434, p=0.003, η^2=0.246). A post hoc test showed a significant difference in mean preferred illuminance between fast-distracted people and the other categories (slowly: p = 0.001, neutral: p = 0.031, somewhat fast: p = 0.026).

Based on the significant effect of the users' sensitivity to distractions on the preferred illuminance, two groups could be created: an average distracted group (n=47) and a fast-distracted group (n=7) of people and the analyses were run again. For the average distracted group, the results for effect of uniformity, as well as luminance on selected illuminances were similar to the total population, with mainly large effect sizes. Results of the paired samples with a significant effect are shown in Table 18 and Table 19. Detailed results of all paired samples are shown in Table B.5 and B.6 Appendix B.

In the small group of fast-distracted people, trends are comparable, but an effect of uniformity on preferred illuminances was only found significant for the minimal start point of the 200 cd/m^2 wall condition (p=0.006). A significant effect of luminance on preferred illuminances was only found between the average 50 cd/m^2 wall condition with the minimal start point and the uniform 200 cd/m^2 wall condition with minimal start point (p=0.007). Due to the small sample size results should be interpreted with caution. However, the large effect size could indicate a trend.

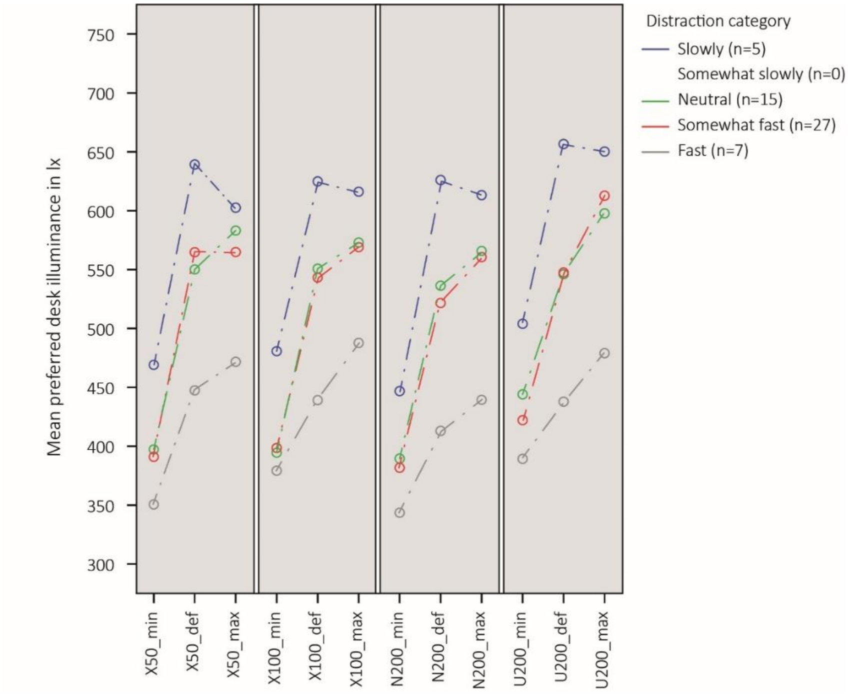


Figure 36. Preferred mean desk illuminance for each condition for different distraction categories.

Table 18. Results paired samples test per distraction group – effect of wall uniformity on the preferred desk illuminance.

	Average distracted group (n=47)		Fast distracted group (n=7)	
	Sig. (2-tailed) [a]	Effect size [b]	Sig. (2-tailed) [a]	Effect size [b]
$N200_{min}$ - $U200_{min}$	0.000	0.57	0.006	0.77
$N200_{def}$ - $U200_{def}$	0.024	0.11	0.223	0.27
$N200_{max}$ - $U200_{max}$	0.000	0.47	0.165	0.33

a) paired samples t-test; b) eta squared: $\eta^2 = t^2/(t^2+N-1)$

Table 19. Results paired samples test per distraction group – effect of average wall luminance on the preferred desk illuminance.

	Average distracted group (n=47)		Fast distracted group (n=7)	
	Sig. (2-tailed) [a]	Effect size [b]	Sig. (2-tailed) [a]	Effect size [b]
$X50_{min}$ - $U200_{min}$	0.000	0.40	0.007	0.76
$X50_{max}$ - $U200_{max}$	0.000	0.26	0.648	0.04
$X50_{min}$ - $N200_{min}$	0.038	0.09	0.331	0.18
$X50_{def}$ - $N200_{def}$	0.005	0.16	0.128	0.38
$X100_{min}$ - $U200_{min}$	0.000	0.32	0.731	0.03
$X100_{max}$ - $U200_{max}$	0.000	0.34	0.727	0.03
$X100_{min}$ - $N200_{min}$	0.005	0.16	0.143	0.36

a) paired samples t-test; b) eta squared: $\eta^2 = t^2/(t^2+N-1)$

4.4. Discussion

In this study, the influence of wall brightness on preferred desk illuminance was explored. In this Section, the strengths and limitations of the study will be discussed.

4.4.1. Study design

The light conditions were not presented to the participants in a completely randomized order, but in one of six sequences. However, analyses showed no effect of the sequence on the users' selected illuminances. Additional analyses of an order effect also showed no significant effects of a previously presented condition. It is therefore not expected that repeating the experiment with a different sequence of conditions would lead to different results.

During the introduction phase at the start of the experiment, the participants could get used to the environmental conditions of the testbed office, to allow the eyes to visually accommodate to the same setting. The study was performed in August and September of 2015. Due to exclusion of daylight and a view and the accommodation time to the space and its atmosphere, it is not expected that an evaluation in a different period of the year would lead to different results.

Different luminaires were used to establish the uniform and non-uniform light conditions in this study. The non-uniform light distribution was achieved by spot light luminaires. Recessed ceiling luminaires in combination with the spots served to illuminate the 'test wall' uniformly. In both, the uniform and the non-uniform conditions, an increasing average wall luminance also led to a decrease of the uniformity U_L, as can be seen in Table 13. Even though the uniformity of the N50 condition was comparable to that of the U200 condition, it was significantly lower than that of the U50 condition, and therefore considered and analysed as a non-uniform condition. The effect of the luminaires' luminance levels on the participants' response (potential glare avoidance) was minimized by choosing luminaires for the study that led to UGR<16 for standard conditions. The different luminaires also resulted in differences in ceiling luminance near the back wall (as can be seen in Figure 33 and Figure 34). A potential influence of this part of the ceiling cannot be disconnected from the results presented here.

4.4.2. Wall conditions

Users' preferred desk illuminances were found to be lower when offering an average wall luminance of 200 cd/m^2 in a non-uniform distribution compared to a more uniform distribution with the same average luminance. For the conditions with an average wall luminance of 50 cd/m^2 or 100 cd/m^2, no significant effect of wall uniformity on the selected desk illuminances was found. The preferred desk illuminances were found to be significantly higher when offering an average wall luminance of 200 cd/m^2 in the more uniform distribution, compared to most other conditions (N200 all, X50, and X100 min max). The differences in users' preferred desk illuminance in the evaluated conditions may have been influenced by a different spatial brightness experience between conditions. As reported in previous studies, the spatial brightness is influenced by, among others, the desk illuminance and the light distribution in the office (de Vries et al., 2015; Duff et al., 2017; Sullivan & Donn, 2016).

The differences in preferred illuminances between people are expressed among other statistics by the interquartile range of each condition. The range in which participants set their preferred task illuminance did not show a consistent difference for the two types of uniformity, nor for the three wall luminance levels. However, the conditions with a low start point for dimming of around 300 lx did show a smaller interquartile range, compared to the conditions with a start point of 500 lx or 700 lx. This suggests that offering a low start point will reduce the difference in preferred task illuminances between occupants. To take people's non-linear perception of light (Illuminating Engineering Society, 2011) into account, the results of the selected illuminances of users are presented on a logarithmic scale in Figure 37.

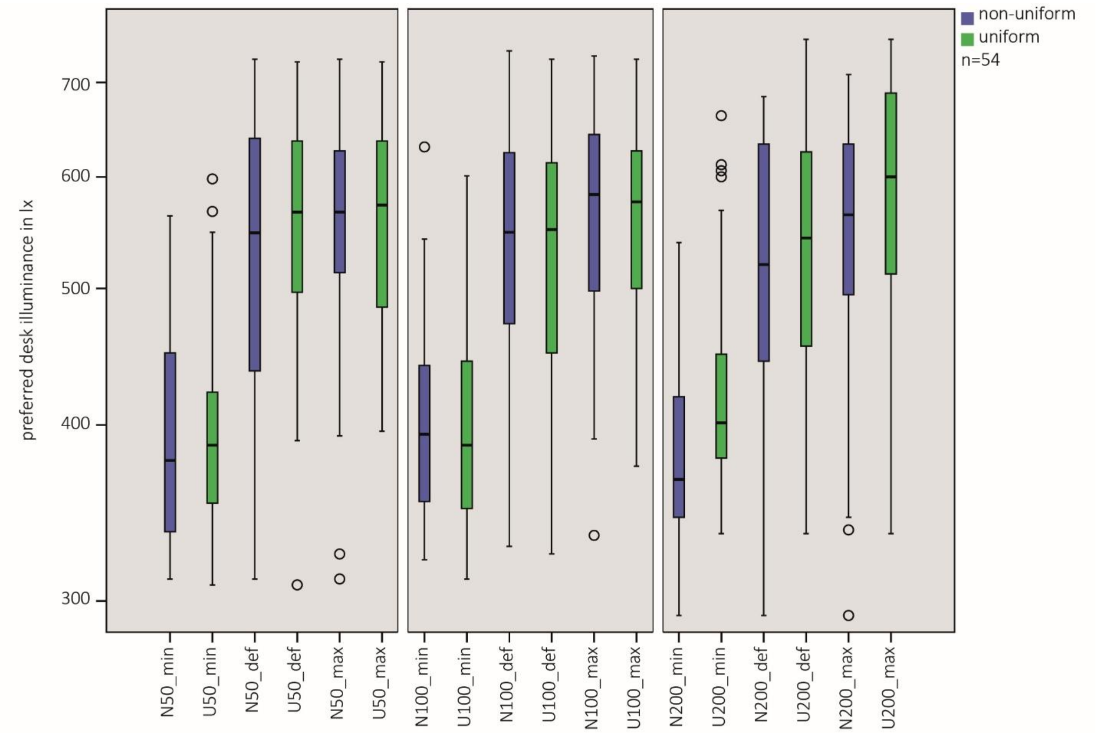


Figure 37. Boxplots of preferred desk illuminance for each wall condition on a logarithmic scale.

When user preferences are plotted on a logarithmic scale to represent perceived brightness, the differences in interquartile range between the conditions is still observable but becomes less obvious. This suggests that for higher preferred illuminances, the spread between people may be larger, without people experiencing these differences as larger.

Satisfaction of participants with the different wall conditions was not quantified in this study. In informal interviews eight participants indicated to prefer a uniformly illuminated wall over a non-uniform wall, two participants indicated to prefer a non-uniformly illuminated wall, and 44 participants did not express a preference. To assess the satisfaction with different levels of wall luminance and uniformity, further research is needed.

The start point from which users were asked to set their preference had a significant effect on the selected task illuminance. For each condition, the mean preferred task illuminance was found to be lowest for the minimum start point, followed by the default and maximal start points, which is in line with the findings of Uttley et al. (2013). In the interviews, participants indicated not to have noticed that only the task illuminance changed when moving to a next start point within the same wall condition. They did not notice the sequence of changing wall conditions every three evaluations.

The self-assessed sensitivity for distractions showed an effect on the preferred illuminances of the users. Figure 36 shows that the more easily users were distracted, the lower their average selected desk illuminance was, with a significant difference between the “fast-distracted” people and the other distraction categories. This could be an indication that fast-distracted people are also more sensitive to light and therefore prefer lower illuminances. Further research is needed to validate these potential relations.

Exploring the possible explanations for the reported effects, the wall conditions were inspected in more detail. A high maximum wall luminance (as present in the N200 condition) could have positively influenced the perceived room brightness, leading to a lower tendency to increase the room brightness by increasing the desk illuminance. This was however not evaluated in the scope of this study. A described potential effect of a high maximum wall luminance would be consistent with the observation that the N200 condition led to a lower average selected illuminance than any of the other conditions, although only significantly for $X50_{min}$, $X50_{def}$, and $X100_{min}$. The study of de Vries et al. (2015) showed that by increasing the wall luminance, the room appraisal increased both in terms of attractiveness and perceived illuminance. The high wall luminance in the study of Newsham et al. (2004) made the space more spacious and attractive. In line with the suggestions of both studies, participants could have been expressing a preference relating to appearance, and to a lesser degree relating to visual comfort. Based on this study it is unclear what the effect of a maximum wall luminance higher than 600 cd/m^2 will be. Additional research on the relation between the assessment of room appearance and the maximum wall luminance is needed for further qualified statements.

The U200 condition had a minimum wall luminance (94 cd/m^2) close to the luminance of the PC monitor (100 cd/m^2) on which the participant performed the task. The absence of background areas with a lower luminance than the task could have contributed to the significantly higher selected desk illuminances in this condition. This suggests that when a contrast between task and background is not observable, users might have the tendency to increase their task lighting, in order to achieve this contrast. This is in line with findings of Sheedy et al. (2005), where preferred surround luminance levels were found to be lower than the luminance of the task. The effect is not found for the conditions with an average wall luminance of 100 cd/m^2, which may be due the presence of areas with a lower luminance than the PC monitor, as can be seen in Table 13, Figure 33, and Figure 34. Additional research is needed to investigate the suggested effect the absence of low luminance background areas could have on selected desk illuminances.

4.5. Conclusions

This study showed that for an average wall luminance of 50 cd/m^2 or 100 cd/m^2, the uniformity of the wall does not influence the selected task illuminance by users. A wall with a non-uniform distributed average luminance of 200 cd/m^2 led to lower selected desk levels than situations with an average wall luminance of 50 cd/m^2 or 100 cd/m^2, both uniform and non-uniformly distributed. A non-uniformly illuminated wall with a high average luminance of 200 cd/m^2 led to lower selected preferred illuminances of users compared to more uniformly illuminated walls with similar or lower average luminance levels.

Results indicate that when provided with controls, users do not only select the lighting required for their visual task but incorporate the observations in their visual field in their selected preference. This study showed that the luminance level and uniformity distributions of the wall in the visual field influence the selected preferred task illuminance of users. The results indicate that high maximum luminance values of the wall in the visual field, lead to lower selected desk illuminance levels. The results also indicate that high minimum luminance values of the wall in the visual field, creating little contrast between the task and the background, lead to higher selected desk illuminance levels.

The start-point for dimming of the task lighting has a significant influence on users' selected task illuminances. A start desk illuminance of around 300 lx led to lower selected illuminances by users than a start desk illuminance around 500 or 700 lx. A start point around 300 lx also led to smaller differences in preferred illuminances between users.

Offering users of open offices personal control with a 300 lx desk level as a starting position to control their desk illuminance, instead of the by standards recommended 500 lx, resulted in 26% lower selected preferred illuminances. Triggering lower selected illuminances, leads to lower energy used for lighting. A 300 lx desk level as a start point has also the potential to reduce the risk of conflict between people due to a smaller range of preferred illuminances. However, more research is needed to confirm that these differences are also perceivable by users, and whether they have an effect on satisfaction ratings of users.

Chapter 5

5. Noticeability and acceptance of granular dimming

This chapter is based on the following publications:

S. Chraibi, P.T.J. Creemers, C. Rosenkotter, E.J. van Loenen, M.B.C. Aries, A.L.P. Rosemann. Dimming strategies for open office lighting: User experience and acceptance. Lighting Research and Technology 2018; 0: 1-17.

P.T.J. Creemers, E.J. van Loenen, M.P.J. Aarts, S. Chraibi, T.A. Lashina. Acceptable fading time of a granular controlled lighting system for co-workers in an open office. Proceedings of Experiencing Light 2014: International Conference on the Effects of Light on Wellbeing, 10-11 November 2014, Eindhoven, The Netherlands

Sensor-triggered control strategies can limit the energy consumption of lighting by considering the presence of users in the office and dimming lighting down when it is not needed. This so-called occupancy-based dimming can be applied at different spatial levels, e.g., room level, zone level, or desk level. At room level, as conventionally used, the lights will dim down when the entire room is unoccupied and dim up as soon as one person is detected in the space. In multi-user offices, the application of occupancy-based dimming at room level limits the energy saving potential. However, zone- or desk-based dimming may affect the comfort of co-workers due to its dynamics. State-of-the-art smart lighting systems more frequently have integrated sensors, enabling the luminaires to detect and respond independently to people's presence at their workplaces. This reinforces the application of occupancy-based dimming at desk level.

This Chapter reports the assessment of occupancy-based dimming at desk level, using different dimming speeds. In a mock-up office two experiments have been conducted with participants of different age groups. Participants consisted of co-workers experiencing changes triggered by others, and actors triggering these light changes. While the participants performed an office-based task, the luminaire above the actors' desk was dimmed from approximately 550 lx to 350 lx (average horizontal illuminance), and vice versa. The participants evaluated the dimming conditions regarding their noticeability and acceptability.

The study showed noticeability of light changes due to dimming, to increase when fading times become shorter. Dimming with a fading time of at least five seconds was not noticed by more than 75% of the participants, irrespective of the dimming direction. Dimming with a fading time of at least two seconds was experienced as acceptable by more than 70% of the participants. Dimming down with a fading time of at least 10 seconds was not noticed by more than 90% of the participants. The results of this experiment provide insights in system behaviour that does not compromise user experience while addressing the energy efficient use of electric lighting.

5.1. Introduction

Lighting uses a significant amount of electricity in office buildings. By considering environmental factors, like the presence of users in the office, sensor triggered control strategies can limit the energy needed for lighting. Consequently, artificial lighting can be dimmed down when it is not needed. This is called occupancy-based dimming and can be applied at different spatial levels, e.g., room, zone, or desk level. Conventionally this is applied at room level, where the lights are dimmed down when the entire room is unoccupied and dimmed up when a person is detected in the space. In private offices this works well, but in today's widely applied multi-user open-plan offices, this limits the energy saving potential. However, when applying dimming in open-plan offices with a zone or desk level granularity, the lighting in the user's visual field becomes dynamic, which introduces the risk of creating uncomfortable situations for users. Building standards provide recommendations for comfortable lighting conditions in office spaces (NEN-EN 12464-1, 2011) and highlight the importance of users' wellbeing (International WELL Building Institute, 2016), but do not give clear guidelines regarding acceptable characteristics of dynamic lighting.

State-of-the-art smart lighting systems more frequently have integrated occupancy and daylight harvesting sensors, enabling control strategies to be applied on individual luminaire level. Each luminaire being able to detect and respond independently to people's presence at their workplaces, reinforces the application of occupancy-based dimming on desk level for energy saving benefits, but it also makes dealing with discomfort more challenging. Considering the perceptible steps as described in the standard EN12464-1 (2011), switching of lighting to a background level will be noticed in most cases, risking dissatisfaction of users present in the space. However, dimming using smooth transitions may be more acceptable. In literature, different studies can be found that address the detection and acceptance of light level reductions, mostly to explore potentials for load-shedding or demand-response lighting strategies to limit the energy used by lighting.

5.1.1. Background

Krzyszczuk and Boyce (2002) reported a study in which they explored how fast the illuminance in an enclosed office space could be reduced before the change was noticed. They used 1095 lx and 475 lx as initial desk illuminance levels, and dimmed down with change rates from 4 to 337 lx/s. In their study, they found that for each given initial illuminance level, there is a relative threshold value for detection of change. For the initial illuminance of 475 lx this was after 22% dimming, and for the initial illuminance of 1095 lx this was after 17% dimming. Although Krzyszczuk and Boyce (2002) reported no effect of speed of change on the detection threshold, Akashi and Neches (2005) do suggest that the dimming speed may allow to further expand the acceptance of illuminance reduction.

Akashi and Neches (2005) evaluated the detection and acceptance of dimming to explore the potential for energy saving by load-shedding. In their studies, subjects detected and evaluated acceptance of dimming while the illuminance was changed from initial illuminance levels of 300 lx and 500 lx to target levels between 20 and 1000 lx. They reported that the probability of detection of illuminance reduction increased as the target illuminance decreased. For dimming down, this meant a higher probability of detection when increasing the dimming speed (from 5 lx/s to 50 lx/s). This effect of increasing dimming speed was also reported for dimming up (Akashi & Neches, 2004). Akashi and Neches (2005) found that once the horizontal illuminance is reduced by more than 20% from the initial level, over 50% of the occupants are likely to detect the reduction. These results are in line with previous studies, that show that 50% of the population could not detect a 15-20% illuminance reduction when engaged in a visual task (Akashi & Neches, 2004; Krzyszczuk & Boyce, 2002; Shikakura, Morikawa, & Nakamura, 2003) and in line with the results from Newsham and Mancini (2006). When a task is performed on a PC screen the sensitivity to illuminance reductions is even lower (Akashi & Neches, 2005). While conducting a PC based task, reductions in illuminance of 40% were still accepted by 80% of the subjects. In the latter study, Akashi and Neches also found that the acceptable dimming range is wider when informing the subjects about the benefits of dimming for load-shedding, compared to the subjects that were not informed. These results demonstrated that tolerance regarding acceptance is greater than the boundaries of detectability. Understanding these differences is important when applying illuminance reductions.

Akashi and Neches (2004) also reviewed the effect of the dimming curve on the detectability or acceptability of illuminance reduction, but reported to have found no effect.

Most of the mentioned studies were conducted in spaces with little or no daylight. Newsham et al. (2008) performed a follow-up study that did include daylight. In the experiment, they dimmed lighting down from the baseline of 400 lx with 0, 20, 40, 60 and 80%, all in 10 s. They showed that in situations with no daylight, the artificial lighting can be dimmed down by 20% without occupants noticing the change and dimmed down by 40% to still be perceived as acceptable. In situations with low to high prevailing daylight, artificial lighting can be dimmed down even further, being respectively 40 and 60% without occupants noticing the change, and by 80% for both, low and high prevailing daylight, while still being perceived as acceptable.

In the above mentioned studies, lighting was dimmed above the subject's desk in a private office set-up (Akashi & Neches, 2004, 2005; Krzyszczuk & Boyce, 2002; Newsham, Mancini, et al., 2008). Even though the study of Shikakura et al. (2003) was performed in a multi-user office space, only one subject at a time participated in the experiment, while the intensity of the luminaire above the subject's desk was altered. The study presented in this Chapter explores the acceptance of occupancy triggered dimming of a single luminaire above a colleague's desk, in the users' visual field. It will include the influence of dimming speed, dimming direction and feedback regarding the reason of dimming, being the change in occupancy.

5.1.2. Hypotheses

Advanced smart lighting systems enable granular dimming of luminaires in open plan office spaces. By dimming down lighting of unoccupied desks the energy efficiency of a lighting system could be enhanced. The rate of change of dimming can influence the energy benefit as well as the user experience, depending on the dimming scenario. Dimming lighting down with a short fading time is most beneficial for energy savings. Noticeable dimming provides an arriving user with the feedback that his presence is observed by the system. However, in open office environments with multiple users, risks of discomfort, due to the introduced dynamics, should be limited. Light changes in the visual field of co-workers, due to granular dimming, could be experienced as disturbing, and therefore acceptable dimming is of importance.

It is hypothesized that the co-workers' acceptance of dimming lighting up or down increases with an increasing fading time. Feedback regarding the reason of an occurring light change is expected to positively influence the acceptance of the change. In case of occupancy-controlled dimming, this feedback could consist of a direct link between the light change and the observation of a person entering or leaving the space. It is therefore believed that the acceptance of dimming directly linked to a change in occupancy is higher than the acceptance of dimming without a direct link to a change in occupancy.

This Chapter presents a study exploring and evaluating occupancy triggered dimming of a single luminaire in a multi user office. Within the study two experiments are conducted to address the hypotheses regarding the co-workers' acceptance of light changes.

5.2. Methodology

Two experiments in a mock-up office have been conducted to evaluate the co-workers' acceptance of illuminance reduction using different dimming speeds. Based on the results of a first study with a student population, a follow-up study was conducted in which a sub-set of the conditions, complemented with additional conditions, were re-evaluated with a group of participants with an age more representative of typical office workers. The office set-up and procedures of the experiments were kept identical. Exposed to the test conditions, participants were asked to perform an office-based task, while an informed actor entered and left the office on instructed moments to simulate a change in occupancy. The experiments were constructed with a repeated measures within-subjects design. *Experiment 1* was conducted in November and December 2013, *experiment 2* in March 2015.

5.2.1. Testbed

The experiments were conducted in a full-scale mock-up office of 7.2 m x 7.2 m x 2.8 m in a laboratory in the Netherlands. The mock-up office was designed to mimic a situation in an open office space. The participants' view included a part of the ceiling, an enclosing wall, multiple other work places, and a cabinet. Each workplace was equipped with a mouse, a keyboard and a 24" LCD monitor, set to an identical screen luminance with an average of 100 cd/m^2. Internal screens blocked daylight entrance, to exclude the impact of exterior light variations on the experiment, and to evaluate the more critical situation without daylight (Newsham, Mancini, et al., 2008). Desks 1-3, as illustrated in Figure 38, were used in the experiments by participants, and desk 4 by an actor who was briefed prior to the experimental sessions. Desk 5 remained unoccupied during the experiments. All subjects had several luminaires in their field of view when looking straight ahead. Additionally, the remaining luminaires were visible when moving their head up or sideways.

The electric lighting system of the mock-up office consisted of six dimmable recessed ceiling LED Luminaires (Philips, PowerBalance, 600 x 600 mm, 4000 K, Ra > 80, UGR<16, 34S, 3400 lm) and ten LED spots (accent lighting, Philips, StyliD 4000 K, Ra > 80, SLED17, 2000 lm). The LED luminaires were installed with DALI drivers, using a logarithmic dimming curve. To evaluate the participants' acceptance of occupancy triggered dimming, luminaire L4 (Figure 38) was dimmed up and down using different dimming rates. To limit the influence of the walls on the perception of the space, the LED spots were used to keep the wall luminance as constant as possible (Chraibi, Crommentuijn, van Loenen, & Rosemann, 2017). During the experiments, the temperature in the office was kept constant at 21°C.

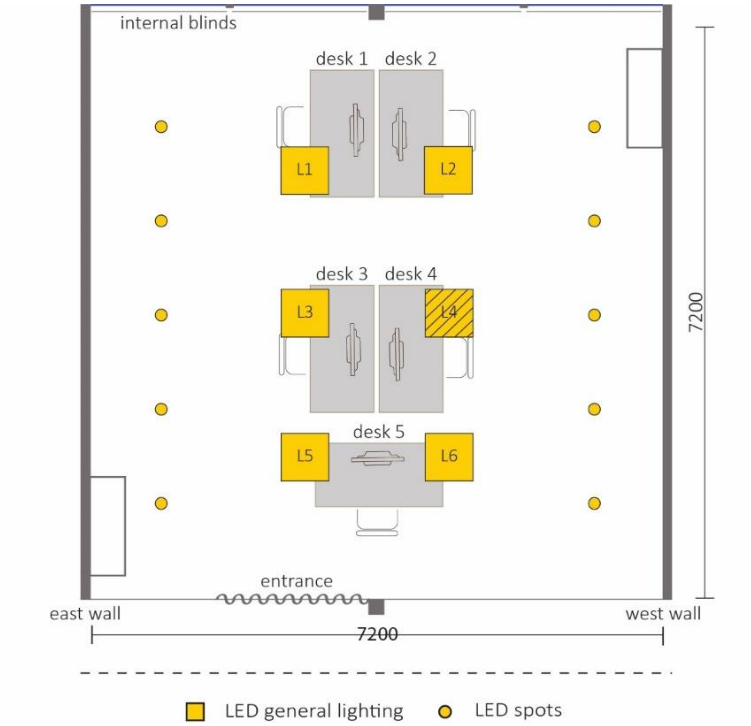


Figure 38. Floorplan of the mock-up office. To simulate occupancy triggered dimming, luminaire L4 was dimmed up and down using different dimming rates.

5.2.2. Participants

The study consisted of two experiments, with two different groups of subjects. All subjects were familiar with office work and had a bachelor's degree or higher. Inclusion criteria included fluency in English, having normal or corrected to normal vision, and no professional knowledge in the field of lighting application or perception. Recruitment was done using flyers with a call for volunteers, distributed at both the technology as well as the university campus of the city.

The subjects of both experiments could be divided in two groups, the "co-workers", also referred to as the participants, experiencing changes triggered by others, and the "actors", entering and leaving the office space on unobtrusively indicated moments. *Experiment 1* was performed with 59 university students in the age range of 18 – 30 years. Three subjects were excluded from the analyses due to drop-out of the actor, which resulted in not being able to execute the experimental sessions according to the designed protocol. Included subjects of *experiment 1* consisted of 41 participants (22 females and 19 males), and 15 actors (eight females and seven males). Based on the results of *experiment 1*, power calculations of the acceptance assessment scale suggested a required sample size of at least 17 participants for *experiment 2*. *Experiment 2* was performed with 27 subjects in the age range from 30 to 50 years. Two subjects of *experiment 2* were excluded from the analyses due to drop-out and prior knowledge of the study objective.

Included subjects consisted of 17 participants (three females and 14 males), and eight actors (four females and four males).

Data of *experiment 1* and *2* was collected in respectively fifteen and eight experimental sessions, all planned on weekday mornings. Each subject participated in one experimental session. Each session had one actor, joined by up to three participants. The actor took place behind desk 4 (Figure 38). Prior to the session, the researcher informed the actor about the study objective. The actor was instructed to enter and leave the office space on specific moments, unobtrusively indicated by the researcher, without communicating to the other users in the office. All data generated by the actors is excluded from the analyses. In each session, the participants took place behind desks 1, 2, or 3 (Figure 38) and were uninformed regarding the different role of the actor and the objective of the experiment. In *experiment 1*, desk 1 was occupied by a participant fourteen times, desk 2 twelve times, and desk 3 fifteen times. In *experiment 2*, desks 1, 2, and 3 were occupied in total respectively six, five, and six times. The information provided to the participants was limited to their involvement in a study assessing user satisfaction in an open office. After the experiment, the participants were fully informed about the study objective. Table 20 shows the characteristics of the participants of both experiments.

Table 20. Characteristics of the participants.

	Gender	Age category	Visual aids
Experiment 1	Female: 22 Male: 19	<20 years: 9 20-24 years: 25 25-29 years: 7	Glasses: 12 Contact lenses: 5 Glasses only when reading or driving: 5 None: 19
Experiment 2	Female: 3 Male: 14	30-35 years: 10 35-40 years: 5 45-50 years: 2	Glasses: 7 Contact lenses: 4 Glasses only when reading: 2 None: 4

5.2.3. Study design

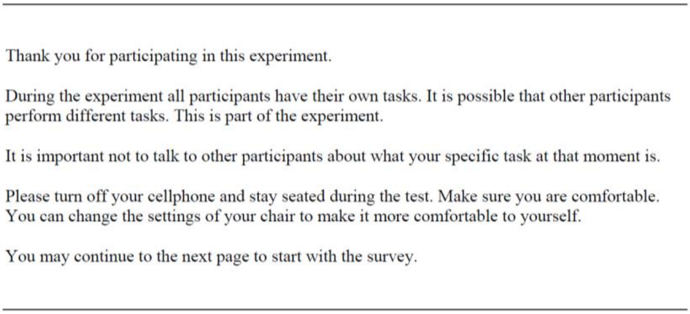
At the day of their participation, the subjects assembled at the reception of the facility, from where they were guided to the laboratory office. In the office, subjects were asked to take place behind their allocated desks, where they received the plenary introduction explaining the procedure of the experiment. Everyone was asked to turn off mobile phones, and not talk to each other during the experiment. In the introduction the objective "an experiment about satisfaction in an open office" was emphasized. Subjects were informed that the experiment will include surveys and a cognitive task. The cognitive task consisted or reading, thinking, and writing, by asking participants to read and summarize an English text presented to them on a PC screen (positive polarity, font size 12). The task represented a typical office task performed in offices nowadays. Subjects did not receive instructions about viewing directions. The subjects were asked to click on a red button, continuously visible at the bottom part of their screen (Figure 39), when they noticed a change in their environment. In the verbal instructions lighting, ventilation, and heating were mentioned as examples. A click on the button triggered an evaluation screen to pop-up in which they could indicate and evaluate the noticed change on a 7-point Likert scale ranging from 'very unacceptable' (1), via 'neutral'

(4) to ‘very acceptable’ (7). As part of the introduction, the on-screen button was pushed by all subjects to get familiar with the options list for noticed changes and with the different screens. The participants were asked to look at the list, which included temperature, ventilation, sound, light, odour, occupancy, and ‘other’, which they could further specify. The participants were not informed that occurring changes would be limited to lighting and occupancy changes only. After providing feedback via the red button, users were instructed to continue with the reading and summarizing task, until the experiment leader informed them to stop (approximately 1.5 hours later).

After the introduction, the subjects were given the opportunity to ask any remaining questions. After that the subjects were asked to start by filling in a demographic survey, which included a repetition of the given instructions (Figure 40). All surveys were presented in English and questions could be answered by the experiment leader in English or Dutch. Subjects were informed that there were no right or wrong answers to either the survey or the task. After the subjects started with the cognitive task, the experiment leader took position outside the test office outside of the view of the participants.

Britain's universities and foreign students

Figure 39. On-screen reading and summarizing task, with the ‘notice’ button to indicate a change when observed.



Thank you for participating in this experiment.

During the experiment all participants have their own tasks. It is possible that other participants perform different tasks. This is part of the experiment.

It is important not to talk to other participants about what your specific task at that moment is.

Please turn off your cellphone and stay seated during the test. Make sure you are comfortable. You can change the settings of your chair to make it more comfortable to yourself.

You may continue to the next page to start with the survey.

Figure 40. On-screen instructions participants had to read before continuing to the survey.

During the reading task, the participants experienced different experimental conditions. Without informing the participants, every 5 or 10 minutes (when the setting incorporated a 5-minute delay), a next condition was started. On specific moments during the experiment, the actor behind desk 4 was discretely asked by the experiment leader to enter or leave the room, using an on-screen chat tool. To simulate occupancy triggered dimming of the lighting above desk 4, luminaire L4 was dimmed up or down accordingly, simulating dimming up when occupancy is detected and dimming down when a desk becomes unoccupied.

The lighting installation was designed to dim up from a background illuminance level of 300 lx to a recommended office task illuminance of 500 lx, and vice versa (NEN-EN 12464-1, 2011). During the study, only luminaire L4 was varied between these respectively 'vacant' and 'occupied' settings. Luminaire L4 was commissioned to deliver a light output as close to these principles as possible. Due to the distance between the luminaires and the properties of the beam, some lighting spill-over did occur, influencing the illuminance level on the other desks as well. Luminaires L1, L2 and L3 remained in the 'occupied' setting of 30% luminaire output, and luminaires L5 and L6 in the 'vacant' setting of 1% luminaire output during the entire experiment. In between *experiment 1* and *2*, the luminaire drivers of the testbed were replaced. Recommissioning of the system resulted in small differences in desk illuminance levels. Table 21 presents the average horizontal illuminance measured on the different desks in the vacant and occupied settings, as well as the illuminance reduction at each desk relative to the desk's initial illuminance level. Figure 41 shows impressions of the room with luminaire L4 in an 'occupied' and 'vacant' state.

Table 21. Overview of the measured average horizontal desk illuminance in the occupied and vacant state.

		$E_{avg,desk1}$ [lx]	$E_{avg,desk2}$ [lx]	$E_{avg,desk3}$ [lx]	$E_{avg,desk4}$ [lx]
Experiment 1	All desks occupied	546	557	545	543
	Desk 4 vacant	510	500	440	310
	% of reduction from initial illuminance	7%	10%	19%	43%
Experiment 2	All desks occupied	571	539	549	543
	Desk 4 vacant	521	489	455	345
	% of reduction from initial illuminance	9%	9%	17%	36%

Figure 41. Impression of the room with luminaire L4 in an 'occupied' state with a horizontal desk illuminance of 543 lx at desk 4 (left) and a 'vacant' state with a horizontal desk illuminance of 310-345 lx at desk 4 (right).

With various fading times, the conditions included dimming up immediately after the actor has entered the room and dimming down with or without a 5-minute delay after the actor has left the office. The delay simulates the delay often used in practice to avoid false detection of an unoccupied desk. To evaluate the influence of the occupancy change, additional conditions were tested, where dimming occurred without an occupancy change, and conditions where the occupancy change did not include a light change.

Based on previous studies (Akashi & Neches, 2004, 2005; Krzyszczuk & Boyce, 2002; Newsham, Mancini, et al., 2008), fading times of 0, 2, 5 and 10 s were selected for *experiment 1*, during which luminaire L4 was dimmed from an average desk illuminance of desk 4 of 310 lx (vacant state) to 543 lx (occupied state), and vice versa. An overview of the evaluated experimental conditions is shown in Table 22. Conditions 1 – 3 and 7, 9 – 13 consisted of a combination of a light and occupancy change. Conditions 4 – 6 and 14, 16 and 17 consisted of only a change in lighting, and conditions 18 and 19 consisted of only an occupancy change. The order of the test conditions was randomized in each experimental session to avoid an order effect. Within the sequences, dimming up is however always followed by dimming down and vice versa, and the same holds for entering and leaving of the actor. In *experiment 1*, each participant experienced each of the 17 different conditions at least once. Due to an unbalance in the number of dimming down and dimming up conditions, some dimming up conditions had to be repeated to be able to dim the lighting down. Figure 42 presents a schematic example of a timeline of an experimental session of *experiment 1*.

After all conditions were evaluated, the participants were informed that only light changes had occurred during the experimental session. The conditions without occupancy changes were thereafter re-evaluated for their noticeability and acceptability while being informed, as also illustrated in Figure 42.

Based on both the previous studies as well as the results of *experiment 1*, fading times of 0, 2 and 5 s were selected for the second experiment, during which luminaire L4 was dimmed from an average desk illuminance of desk 4 of 345 lx to 543 lx, and vice versa. *Experiment 2* included 14 experimental conditions, shown in Table 22. For *experiment 2*, dimming down in 10 s was replaced by conditions in which luminaire L4 was dimmed in 5 s. The conditions in which dimming down was executed without a delay were not included in *experiment 2*. Labels of similar conditions were kept identical to *experiment 1*. Each participant experienced each of the 14 different conditions once. The conditions 4 - 6 and 14 – 16 consisted of only a change in lighting. The conditions 18 and 19 consisted of only an occupancy change, and the conditions 1 - 3 and 7 - 9 consisted of a combination of a light and occupancy change. In each of the eight experimental sessions, a different order of the conditions was used. Within the sequences, dimming up is always followed by dimming down and vice versa, and the same holds for entering and leaving of the actor. Figure 43 presents a schematic timeline of an example sequence of the experienced conditions during one of the experimental sessions of *experiment 2*.

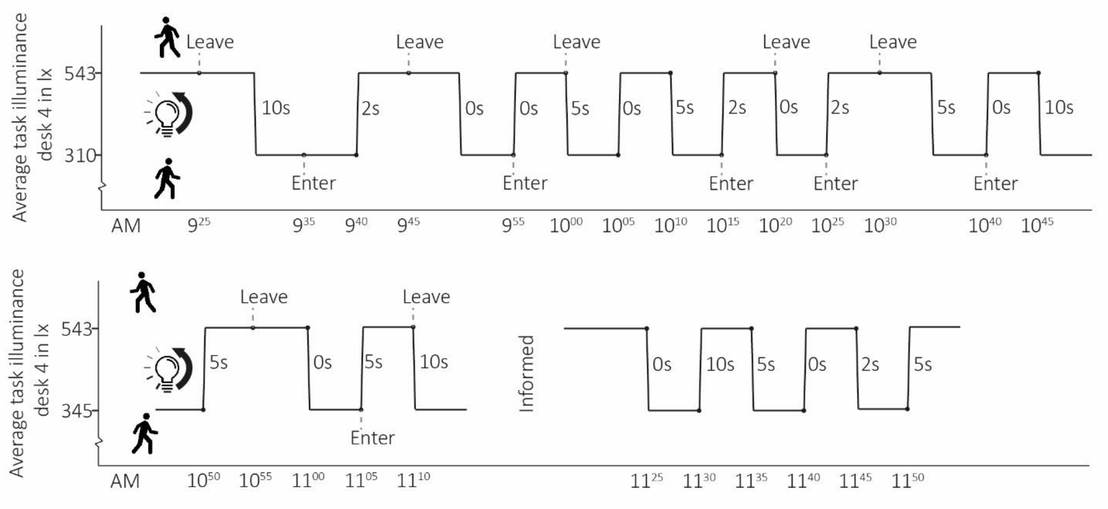


Figure 42. Schematic timeline of the conditions in an example experimental session of experiment 1, including the moments the actor entered or left the office, and the direction and speed of the light changes.

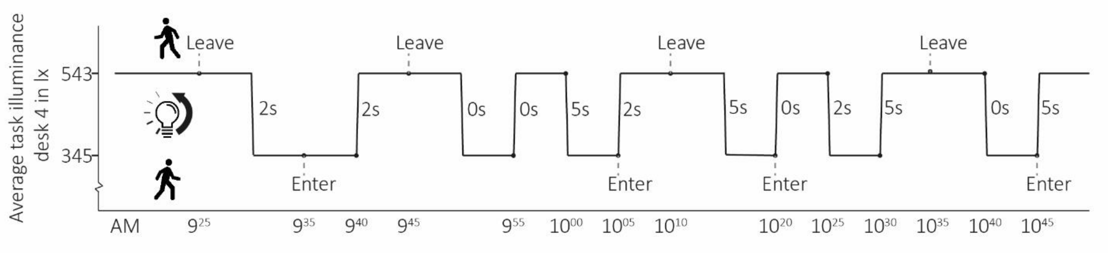


Figure 43. Schematic timeline of an example sequence of the experienced conditions in one of the experimental sessions of experiment 2, including the moments the actor entered or left the office, and the direction and speed of the light changes.

Table 22. Characteristics and labels of the evaluated conditions of experiment 1 and 2. The evaluated conditions include variations in occupancy change, and direction and speed of the light change.

Conditions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Lights	Dim up						Dim down											No change	
Actor	Enters			No change			Leave [b]				Leave			No Change				Enter	Leave
Fading Time [a] [s]	0	2	5	0	2	5	0	2	5	10	0	5	10	0	2	5	10	-	-
Experiment 1	○	○	○	○	○	○	○		○	○	○	○	○	○		○	○	○	○
Experiment 2	●	●	●	●	●	●	●	●	●					●	●	●		●	●

a) Time to dim up or down from the vacant state to the occupied state or vice versa
b) Lights are dimmed down 5 min after the actor has left the office

Even though the system was commissioned to dim instantaneously (i.e., within 0 s), the actual measured dimming took more time. Table 23 shows the actual fading time and dimming speed of the conditions, measured with a 0.09 s interval, which was the fastest possible sampling rate of the measurement equipment. Even though the exact fading times deviate, the rounded numbers, 0 – 2 – 5 – 10, will be used throughout this Chapter when referring to the different dimming behaviours.

Table 23. Fading times evaluated in the study.

	Dim up			Dim down			
	0	2	5	0	2	5	10
Actual fading time [s]	0.27	1.71	4.86	0.36	1.71	4.86	9.99
Dimming speed [lx/s] [a]	822	133	45	605	133	45	22

a) Calculated slope of the dimming curve trendline

5.2.4. Metrics

When participants noticed a change, they were prompted to evaluate it on a 7-point Likert scale ranging from ‘very unacceptable’ [1], via ‘neutral’ [4] to ‘very acceptable’ [7]. The 7-point scale was selected to allow for more discrimination in the ratings and more granularity in the results. For the analyses of this study, this 7-points scale is extended to an 8-points acceptance scale. When a light change was not noticed by a participant, it is labelled with the highest rating for acceptance: ‘not noticed’ [8]. The noticeability is analysed on a two-point scale, using the assigned values “noticed” [1] and “not noticed” [0].

Due to the ordinal character of the data and the relatively small sample size, the data was analysed using non-parametric statistics. Data is analysed for an effect of the independent variables, by means of a Mann-Whitney test (two independent groups) and a Kruskal-Wallis test (three or more groups). Within-subjects Friedman tests (repeated measures at three or more points in time) and Wilcoxon Signed Ranks tests (repeated measures at two occasions) are used to explore effects of the dimming direction, speed and occupancy change. Effect size calculations are done using Pearson *r*, calculated using $r=Z/\sqrt{N}$ of Rosenthal (1994) (from: Field, 2009). Interpretation of the values is done following guidelines of Cohen (1988), with 0.1=small effect, 0.3=moderate effect, and 0.5=large effect.

5.3. Results

In this Chapter, results of *experiment 1* and *experiment 2* will be discussed separately.

5.3.1. Experiment 1

During all experimental sessions of *experiment 1*, in total 852 changes were reported by the participants, of which 421 were light changes and 229 were occupancy changes. Of these reported occupancy changes, 55 were reported as other but specified as “person entering or leaving the office”. Table 24 presents all reported changes. The remaining “other” changes, reported by three individuals, included sneezing co-workers or chairs being changed in height, as well as 14 indications of changing PC screen brightness. The analyses presented here focusses on the indications of light changes only. 41% of the executed light changes in *experiment 1* were reported as noticed by the participants.

Due to a disbalance in the number of dimming down and dimming up conditions, some dim up conditions were repeated to be able to subsequently dim the lighting down. Each participant evaluated two dimming up conditions twice, resulting in additional evaluations of the conditions 1, 2, 3, 4, and 6. A within-subjects analyses showed no significant difference between the first and second time a participant evaluated a condition (detailed results of the statistical analyses are shown in Table C.1 Appendix C). In further analyses only the first evaluations of all conditions were used, discarding all second evaluations.

Table 24 Changes reported by the participants during the experimental sessions of experiment 1.

Reported change	Quantity
Temperature	64
Ventilation	20
Sound	90
Light	421
Odour	3
Occupancy	229
Other	25

5.3.1.1. Independent variables

The design of the study enclosed several independent variables, which were evaluated for their effect on the noticeability and acceptance of the light changes. Experimental sessions were executed on different weekdays. The day on which each experiment was conducted did not affect the noticeability or acceptance ratings (p>0.05). The experiment included 19 male and 22 female participants. The gender of the participants did also not affect the noticeability or acceptance ratings ($p>0.05$). Within the selected participant age group of 18-30 years, a subdivision into three groups was made, distinguishing participants younger than 20 years, from 20 to 24 years and from 25 to 29. Age did not show an effect on the acceptance ratings but did show an effect on noticeability of one of the conditions. Dimming up in two seconds, without a change in occupancy, was noticed significantly more often ($Z=6.491$, $p=0.041$) by the participants in the middle age category (mean=0.52, SD=0.510), compared to the other groups (both mean=0.13, SD=0.354). The desk behind which the participant took place during the experiment affected the noticeability and acceptance ratings of multiple conditions. Light changes were most frequently noticed by users behind desk 3 (59% of the executed changes), and less frequently by users behind desk 1 and 2 (33% and 28% of the executed changes respectively) (Table 25). The acceptance ratings follow that same pattern, with the lowest mean acceptance rating for desk 3. Figure 44 shows the distributions of acceptance levels for the different desks in boxplots. The results of the conditions in which the desk significantly affected the user ratings are presented in Table 26. It should be noted that even though equal desk occupation was pursued, desk 1 was occupied fourteen times, desk 2 twelve times and desk 3 fifteen times. Due to the number of occupations per desk, no subdivision based on desk was made in further analyses.

Table 25. Frequencies of noticed light changes per desk in experiment 1

Desk	*Noticed*	*Not noticed*	*Total*
1 (n=14)	98	196	294
2 (n=12)	70	182	252
3 (n=15)	186	129	315

Table 26. Results of the statistical tests showing the effect of the workplace on the noticeability and acceptance of the experimental conditions in experiment 1.

	Condition	*2*	*3*	*5*	*6*	*10*	*12*	*16*
Noticeability	X^2 Value [a]	8.547	14.275		6.987	7.495	7.495	11.040
	Sign. (2-tailed)	.014	.001		.030	.024	.024	.004
Acceptance	X^2 Value [a]	8.749	14.121	7.456	7.284	7.481	7.471	11.374
	Sign. (2-tailed)	.013	.001	.024	.026	.024	.024	.003

a) Kruskal-Wallis Test, Chi-Square value ($p<0.05$) with df=2.

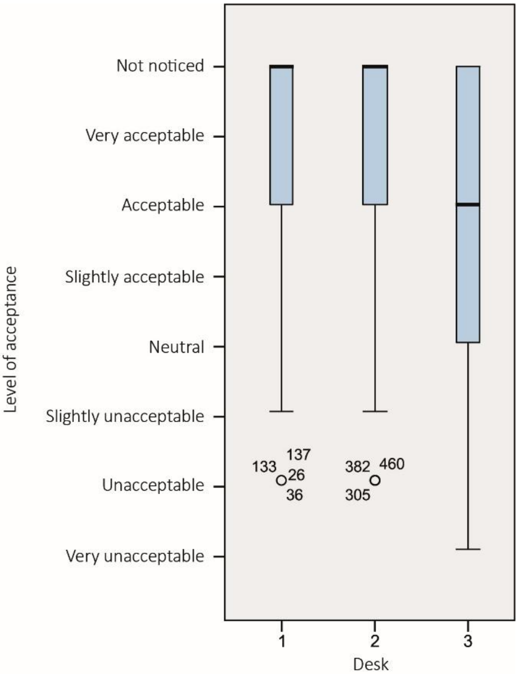


Figure 44. Acceptance distributions of experiment 1, plotted per desk in boxplots (n=14, 12, and 15 for desks 1,2, and 3). Desks 1 and 2 show higher acceptance ratings with median values at the highest acceptance level.

5.3.1.2. Ratings of acceptance

Distributions of the participants' ratings of acceptance of the light changes are presented in the boxplots of Figure 45. As can be seen, immediate dimming, with a fading time of 0 s, was noticed by most participants. The conditions with a 5 s and 10 s fading time were scarcely noticed. Table 27 presents the mean and standard deviation values of acceptance of each condition.

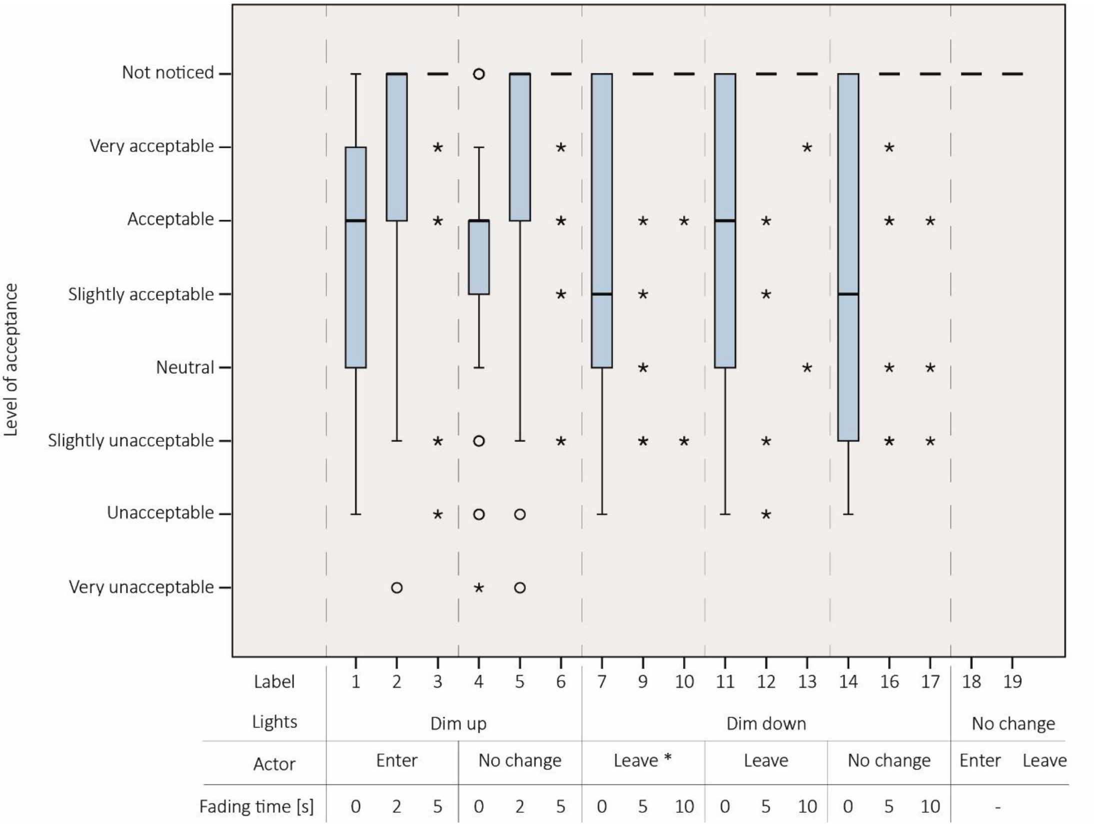


Figure 45. Results of the evaluated conditions of experiment 1 plotted in a boxplot. Conditions are sorted on ascending label numbers. Characteristics of each condition are shown in the table at the bottom of the boxplot. Within the subgroups, indicated with the dotted line, the median values show increasing acceptance with increasing fading times.
** Lights are dimmed down 5 min after the actor has left the office*

Table 27. Mean and standard deviation of the acceptance level values of each condition of experiment 1. The acceptance scale ranges from 1 to 8, with higher values for higher acceptance ratings.

Conditions	1	2	3	4	5	6	7	9	10
Mean	5.54	6.90	7.46	5.51	6.78	7.44	5.17	6.95	7.59
SD	1.925	1.908	1.451	1.804	1.930	1.305	2.048	1.936	1.341

Conditions	11	12	13	14	16	17	18	19
Mean	5.51	7.61	7.88	5.27	7.29	7.73	8.00	8.00
SD	2.087	1.302	.640	2.062	1.616	1.025	0.000	0.000

5.3.1.3. Impact on noticeability and acceptance

In the following paragraphs, the elements dimming speed, dimming direction, occupancy change, and informing the participants are analysed for their impact on the acceptance ratings of the light changes.

Dimming speed

The boxplots of Figure 45 suggests an increase in acceptance level with an increasing fading time for dimming, observable by the median values within each subgroup. Using only the fading time as a variable, five groups were formed to analyse the effect of dimming speed on acceptance. A first group of conditions in which a person entered the office and lighting was dimmed up immediately, using three fading times (conditions 1-2-3). A second group in which lighting was dimmed up using three fading times without a change in occupancy (conditions 4-5-6). A third group of conditions in which a person left the office, followed by lighting dimmed down and after a five minutes delay, using three fading times (conditions 7-9-10). A fourth group in which a person left the office and lighting was dimmed down immediately (without the delay) using three fading times (conditions 11-12-13), and a fifth group with lighting dimmed down using three fading times without a change in occupancy (conditions 14-16-17).

The analysis showed an effect of dimming speed on the noticeability and acceptance levels of the conditions, within all formed groups. Detailed results of the statistical analyses are shown in Table C.2 Appendix C. Post hoc tests, with a Bonferroni correction (significance of $p<0.0167$) were performed on the acceptance ratings to analyse between which fading times within each group these effects occur. Results of the combinations with a significant effect are reported in Table 28. As can be seen, effects observed are all, but one, of a large size (using guidelines of Cohen (1988), with 0.1=small effect, 0.3=moderate effect, and 0.5=large effect).

Table 28. Results of the post hoc tests showing the conditions of experiment 1 where dimming speed showed an impact on the acceptance ratings.

Conditions	2 – 1	3 – 1	5 – 4	6 – 5	4 – 6
Z [a]	-3.472[c]	-4.591[c]	-3.256[c]	-2.724[c]	-4.600[d]
Asymp. Sig. (2-tailed) [a]	0.001	0.000	0.001	0.006	0.000
Effect size [b]	-0.54	-0.72	-0.51	-0.43	-0.72

Conditions	9 – 7	7 – 10	12 – 11	11 – 13	16 – 14	14 – 17
Z [a]	-4.020[c]	-4.199[d]	-4.105[c]	-4.646[d]	-4.453[c]	-4.712[d]
Asymp. Sig. (2-tailed) [a]	0.000	0.000	0.000	0.000	0.000	0.000
Effect size [b]	-0.63	-0.66	-0.64	-0.73	-0.70	-0.74

a. Wilcoxon signed-rank tests, with a Bonferroni correction ($p<0.0167$), b. Pearson r, calculated using $r=Z/\sqrt{N}$ *of Rosenthal (1994) (from: Field, 2009), c. based on negative ranks, d. based on positive ranks*

As can be seen in Table 28, the tests showed all groups to have a significant difference in acceptance of fading in 0 s versus any other fading time. When dimming up without an occupancy change, acceptance of fading in 2 s was significantly lower than with a 5 s fading time. This difference was not observed when dimming was accompanied with a change in occupancy. No significant difference was found between acceptance ratings for 5 s fading versus 10 s.

Dimming direction

Using only the dimming direction as a variable, groups were formed to analyse the effect of the direction of dimming on the acceptance level. To exclude the impact of a person walking in, respectively leaving the office, only the conditions without an occupancy change and with the same dimming speed were considered. These are dimming in 0 s (conditions 4-14) and dimming in 5 s (conditions 6-16). The tests showed no significant effect of dimming direction on the acceptance of the light changes (p>0.05). Detailed results of the statistical analyses are shown in Table C.3 Appendix C.

Occupancy change

Using only the occupancy change as a variable, the data was analysed for an effect of occupancy change on the acceptance level of the light change. Pairs were formed to compare the conditions with vs without an occupancy change. Three pairs were formed of the conditions dimming up with similar fading times (conditions 1-4, 2-5, and 3-6). Six pairs were formed of the conditions dimming down with similar fading times after a delay (conditions 7-14, 9-16, and 10-17) and without a delay (conditions 11-14, 12-16, and 13-17). All pairs tested, showed no significant effect of occupancy change on the acceptance of dimming (p>0.05). Detailed results of the statistical analyses are shown in Table C.4 Appendix C.

Delay

Using only the delay introduced for dimming down as a variable, the data was analysed for an effect of the delay on the acceptance level of the light change. Three pairs were formed of dimming down conditions with similar fading times: dimming down in 0 s (conditions 7-11), dimming down in 5 s (conditions 9-12) and dimming down in 10 s (conditions 10-13). The tests showed a significant effect of the delay on noticeability and acceptance for one of the conditions. Dimming down in 5 s was noticed more often (p=0.034, Z=-2.121, *r*=-0.33) and rated lower in acceptance (p=0.037, Z=-2.083, *r*=-0.33) when fading was done with a 5 min delay after the occupant left the office space, however both with a medium effect size. No significant effect of a delay was found on noticeability or acceptance ratings for dimming in 0 or 10 s. Detailed results of the statistical analyses are shown in Table C.5 Appendix C.

Informing the participants

After all conditions were evaluated, participants were informed that only light changes could occur. The three fading times of dimming up and the three fading times of dimming down were thereafter re-evaluated in a random order, without an occupancy change. Table 29 shows the descriptive statistics of the informed conditions.

Table 29 Descriptive statistics of the acceptance ratings of the informed conditions.

	Dim up – no occupancy change			Dim down – no occupancy change		
Fading time [s]	0	2	5	0	5	10
Condition	4.I	5.I	6.I	14.I	16.I	17.I
Mean	5.32	6.29	6.66	5.12	6.95	7.68
SD	1.665	1.940	1.726	1.706	1.702	1.035

By making pairs with their uninformed counter conditions (similar dimming direction, fading time, and occupancy change), the effect of informing participants on acceptance ratings was tested. The tests showed being informed to only significantly effect noticeability and acceptance of one of the conditions. Dimming up in 5 s was noticed more often (p=0.04, Z=-2.887, *r*=-0.45) and rated lower in acceptance (p=0.003, Z=-2.940, *r*=-0.46) when participants were informed of the possibility of light changes occurring compared to not being informed, both with a medium to large effect size. Detailed results of the statistical analyses are shown in Table C.6 Appendix C.

5.3.1.4. Acceptable dimming

To create an overview of acceptable conditions, ratings of ‘acceptable’ [6] or higher were isolated and plotted for each condition. Figure 46 shows the percentage of participants that evaluated a condition within this higher part of the scale. Ratings of ‘slightly acceptable’ and lower are considered unacceptable. The overview clearly shows that for most conditions, a substantial part of the acceptable changes consist of light changes that were not noticed by the participants.

The results of *experiment 1* showed, when applying occupancy-based dimming with a short fading time (0-seconds condition), less than 55% of the users experienced the conditions as acceptable. The level of acceptance reduced even further (<40%) when dimming was applied with a delay after a user leaves the office. Applied without a time delay after the user leaves his desk, acceptance of dimming was higher, which corresponds to the findings of Akashi and Neches (2005), reporting that feedback regarding the occurred change could enhance the acceptance of the users.

Implementing dimming up with a fading time close to two seconds and dimming down with a fading time close to five seconds resulted in acceptance by more than 75% of the users. Akashi and Boyce (2006) reported that with static lighting, 70% of the office workers in a typical US office is satisfied with the lighting. The acceptance ratings of Figure 46 show that a similar threshold can be reached for acceptance of dynamic lighting using a dimming speed of at least 2 s when dimming up, and 5 s when dimming down.

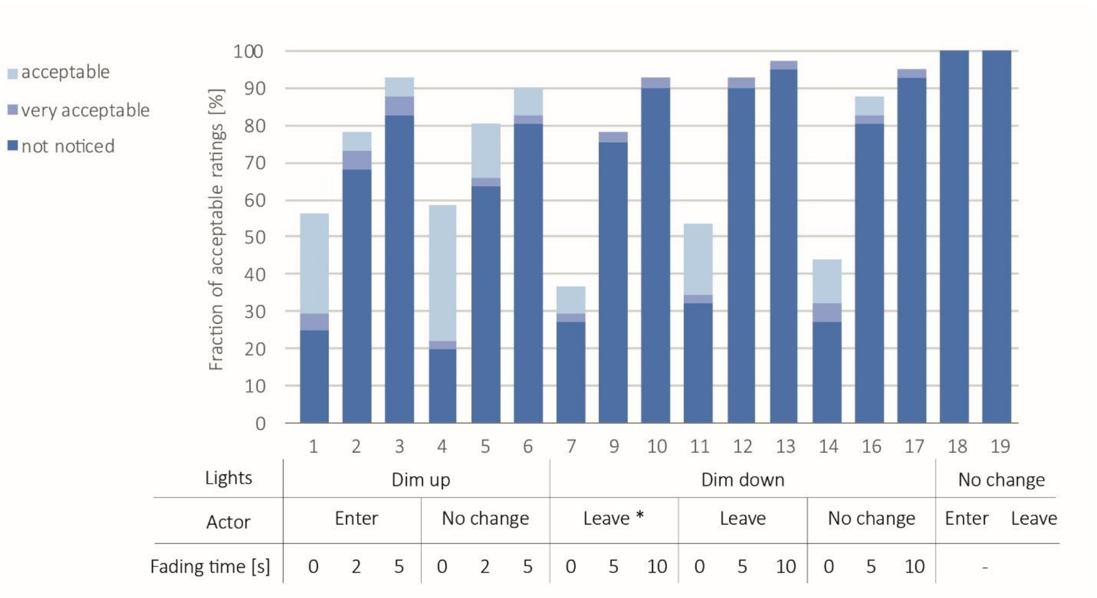


*Figure 46. Fraction of participants that rated lighting conditions as acceptable, very acceptable, or not noticed in experiment 1. Conditions are sorted on ascending label numbers. Characteristics of each condition are shown below the bar chart. * Lights are dimmed down 5 min after the actor has left the office.*

5.3.2. Experiment 2

During all experimental sessions of *experiment 2*, a total of 232 changes were reported by the participants, of which 88 were light changes and 65 were occupancy changes (of which 51 were indicated as an occupancy change and 14 as other but specified as person entering or leaving the office). Other indications existed of temperature (21 indications), noise levels (42 indications), ventilation (13 indications), or other (3 indications). 43% of the executed light changes in experiment 2 were reported as noticed by the participants.

5.3.2.1. Independent variables

The ratings of noticeability and acceptance showed no significant effect for gender, age category, or day of the week on which the experiments were conducted (p>0.05). The desk behind which the participant took place during the experiment did show an effect on the noticeability and acceptance ratings for multiple conditions. Light changes were most frequently noticed by users behind desk 3, and least frequently by users behind desk 1 (Table 30). The acceptance ratings follow that same pattern with desk 3 scoring lowest on mean acceptance ratings, and desk 1 highest. Figure 47 shows the distributions of acceptance levels for the different desks in boxplots. Conditions in which the desk of the participants had a significant effect on noticeability or acceptance are shown in Table 31. It should be noted that even though equal desk occupation was pursued, desk 1 and 3 were occupied six times, and desk 2 five times. Due to the small sample size, no subdivision based on workplace was made in further analyses.

Table 30. Frequencies of noticed light changes per desk in experiment 2.

Desk	Noticed	Not noticed	Total
1 (n=6)	21	63	84
2 (n=5)	21	49	70
3 (n=6)	39	45	84

Table 31. Results of the statistical tests of the conditions in experiment 2 with an effect of the workplace on the noticeability and acceptance of the experimental conditions.

	Noticeability			Acceptance	
Condition	1	3	6	3	6
X^2 Value [a]	9.269	6.286	6.286	6.216	6.233
Sign. (2-tailed)	0.010	0.043	0.043	0.045	0.044

a) Kruskal-Wallis Test, Chi-Square value (p<0.05) with df=2.

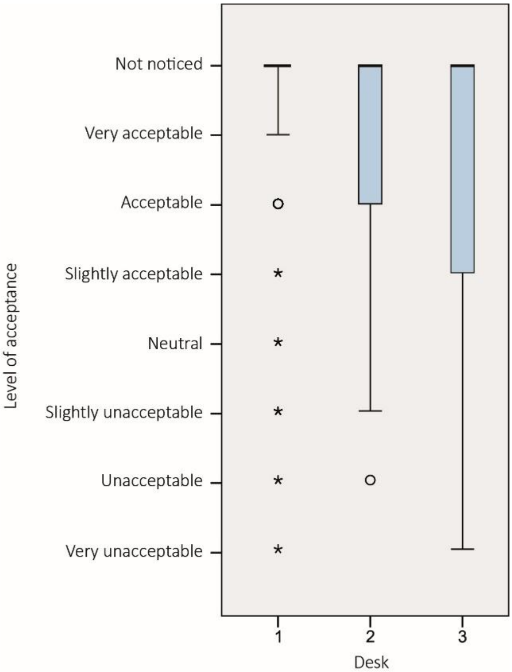


Figure 47. Acceptance distributions experiment 2, plotted per desk in boxplots (n=6, 5, and 6 for desks 1, 2, and 3). Desks 1, 2, 3 show a descending acceptance. All desks have median values at the highest acceptance rating.

5.3.2.2. Ratings of acceptance

Distributions of the participants' ratings of acceptance of the light change are presented in the boxplots of Figure 48. As can be seen, immediate dimming, with a fading time of 0 s, was noticed by most participants. The conditions with 5 s fading time were scarcely noticed. Table 32 presents for each condition the mean and standard deviation values of acceptance.

Table 32. Mean and standard deviation of the acceptance level values of each condition in experiment 2. The acceptance scale ranges from 1 to 8, with higher values for higher acceptance ratings.

Conditions	1	2	3	4	5	6	7
Mean	5.76	6.41	7.35	4.35	6.65	7.59	5.12
SD	1.985	2.123	1.618	1.902	1.967	0.939	2.315

Conditions	8	9	14	15	16	18	19
Mean	7.53	7.41	5.65	7.06	7.88	8.00	8.00
SD	1.505	1.326	2.120	1.853	0.458	0.000	0.000

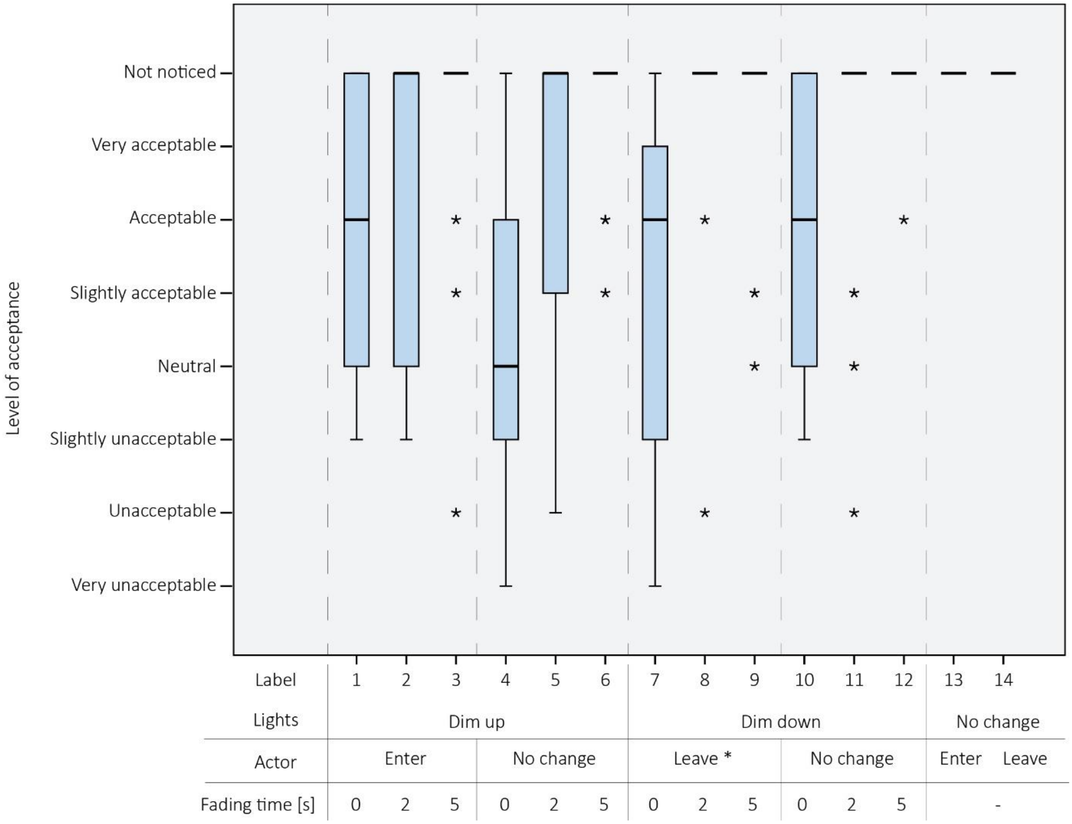


*Figure 48. Results of the evaluated conditions of experiment 2 plotted in a boxplot. Conditions are sorted on ascending label numbers. Characteristics of each condition are shown in the table at the bottom of the boxplot. Within the subgroups, indicated with the dotted line, the median values show increasing acceptance with increasing fading times. * Lights are dimmed down 5 min after the actor has left the office.*

5.3.2.3. Impact on noticeability and acceptance

In the following paragraphs, the impact of dimming speed, dimming direction, and occupancy change on the acceptance ratings of the light changes was analysed.

Dimming speed

The boxplots of Figure 48 suggest an increase in acceptance level with an increasing fading time for dimming, observable by the median values within each subgroup. Using only the fading time as a variable, four groups were formed to analyse the effect of dimming speed on acceptance. A first group experiencing the situation in which a person entered the office and lighting was dimmed up immediately, using three fading times (conditions 1-2-3). A second group experiencing lighting dimmed up using three fading times without a change in occupancy (conditions 4-5-6). A third group experiencing the situation in which a person left the office and after a five minutes delay lighting was dimmed down using three fading times (conditions 7-8-9), and a fourth group experiencing lighting dimmed down using three fading times without a change in occupancy (conditions 14-15-16).

The analyses showed an effect of dimming speed on the noticeability and acceptance levels for all conditions. Detailed results of the statistical analyses are presented in Table C.7 Appendix C. Post hoc tests, with a Bonferroni correction (significance of $p<0.0167$) were performed on the acceptance ratings to analyse between which fading times these effects occurred. Only results of the combinations that showed a significant effect are reported in Table 33, all have a large effect size.

Table 33. Results of the post hoc tests showing the conditions where dimming speed showed an impact on the acceptance ratings.

Conditions	3 – 1	5 - 4	4 - 6	8 - 7	7 – 9	14 – 16
Z [a]	-2.567 [b]	-3.189 [b]	-3.432 [c]	-3.201 [b]	-3.205 [c]	-2.953 [c]
Asymp. Sig. (2-tailed) [a]	0.010	0.001	0.001	0.001	0.001	0.003
Effect size [d]	-0.62	-0.77	-0.83	-0.78	-0.78	-0.72

a. Wilcoxon signed-rank tests, with a Bonferroni correction ($p<0.0167$), b. based on negative ranks, c. based on positive ranks, d. Pearson r, calculated using $r=Z/\sqrt{N}$ *of Rosenthal (1994) (from: Field, 2009).*

The tests showed for all groups, a significant difference in acceptance of fading in 0 s versus 5 s. The ratings of the 2 s conditions were always in between the ratings of 0 s and 5 s, as can be seen in the boxplots of Figure 48. None of the groups showed a significant difference between 2 s and 5 s fading. For dimming up without an occupancy change and dimming down after an occupancy change, a significant difference between fading in 0 s and 2 s was found.

Dimming direction

Using only the dimming direction as a variable, four groups were formed to analyse the effect of the direction of dimming on the acceptance level. To exclude the impact of a person entering or leaving the office (5 min prior to the light change due to the delay), only the conditions without an occupancy change were considered, being dimming up and down in 0 s (conditions 4-14), 2 s (conditions (5-15), and 5 s (conditions (6-16). The tests showed only an effect of dimming direction on the noticeability of dimming in 0 s, with a large effect size ($p=0.025$, $Z=-2.236$, $r=-0.54$). The tests showed no significant effect of dimming direction on the acceptance level. Results of the statistical analyses are presented in Table C.8 Appendix C.

Occupancy change

Using only the occupancy change as a variable, the data was analysed for an effect of occupancy change on the acceptance level of the light change. Six pairs were formed of conditions with similar dimming directions and fading times, with the occupancy change as a variable, comparing with to without an occupancy change. The formed pairs consisted of three pairs of dimming up with respectively 0, 2, and 5 s (conditions 1-4, 2-5, and 3-6), and three pairs of dimming down after a delay with respectively 0, 2, and 5 s (conditions 7-14, 8-15, and 9-16).

The tests showed no significant effect of occupancy change on noticeability of dimming ($p>0.05$) and no significant effect on dimming acceptance in all but one condition. Dimming up in 0 s was rated more acceptable when accompanied with an occupancy change, with a large effect size ($p=0.006$, $Z=-2.742$, $r=-0.67$). Results of the statistical analyses are presented in Table C.9 Appendix C.

5.3.2.4. Acceptable dimming

To create an overview of acceptable conditions, ratings of 'acceptable' [6] or higher were isolated and plotted for each condition. Figure 49 shows the percentage of participants that evaluated a condition within this higher part of the scale. Ratings of 'slightly acceptable' and lower were considered unacceptable. The overview clearly shows, the acceptable conditions to a substantial extent to consist of light changes that are not noticed by the participants.

Akashi and Boyce (2006) reported that with static lighting, 70% of the office workers in a typical US office is satisfied with the lighting. When using this same threshold of satisfied users, similar levels can be reached for acceptance of dynamic lighting using a dimming speed of at least 2 s.

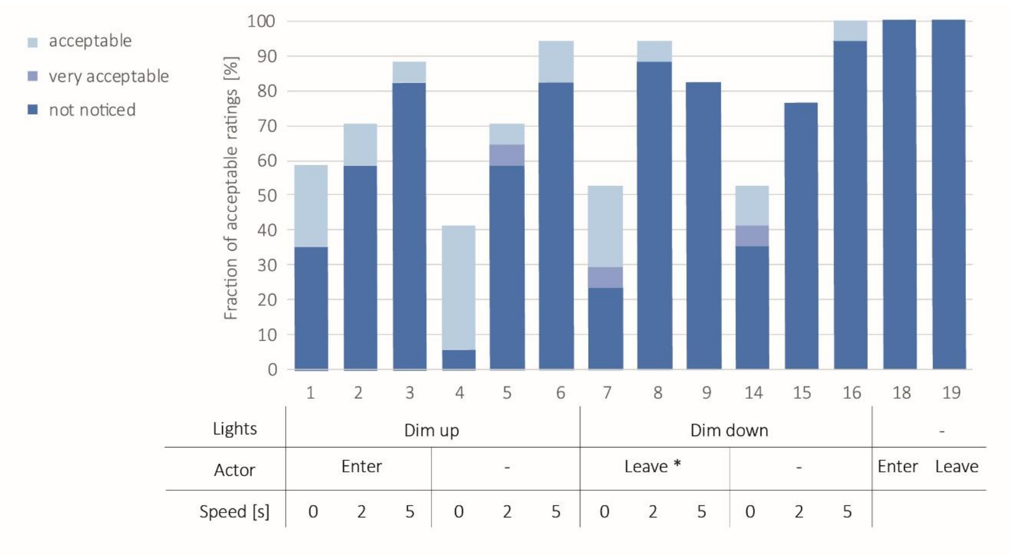


*Figure 49. Fraction of participants that rated lighting conditions as acceptable, very acceptable, or not noticed in experiment 2. Conditions are sorted on ascending label numbers. Characteristics of each condition are shown below the bar chart. * Lights are dimmed down 5 min after the actor has left the office.*

5.4. Discussion

In this study, occupancy-based dimming was used to evaluate the noticeability and acceptance of dimming of a single luminaire in the user's visual field. In this Section, the strengths and limitations of the study will be discussed.

5.4.1. Study design

Experiment 1 was executed with a group of 41 while *experiment 2* was executed with a relatively small sample size. However, as calculated in advance based on the results of *experiment 1*, 17 participants for *experiment 2* appeared sufficient to show significant differences between the tested conditions. Both experiments showed similar percentages of noticed light changes. Respectively 41% and 43% of the executed changes in *experiment 1* and *2* were reported as noticed by the participants. Both studies were comparable in the effect of the independent variables on the noticeability and acceptance ratings of the light changes. In the analyses of both experiments, no subdivision based on workplace was made. However, the desk behind which the participants evaluated the conditions did show to influence the acceptance of light change ratings, with lower acceptance of dimming at desk 3 compared to desks 1 and 2. Due to the office layout and lighting characteristics this effect is not surprising. Desk 3 was most influenced by the absolute desk illuminance reduction when dimming, due to lighting spill-over from luminaire L4 (Table 21). Additionally, the users behind desk 3, (facing desk 4) had luminaire L4 in their direct field of view (Figure 38). Desks 1 and 2 were situated next to desks 3 and 4, with a spacing in between, experiencing less influence from the lighting spill-over and had luminaire L4 and desk 4, both subjects of change, less prominently in their visual field.

When considering users of all three workplaces, less than 60% of the users experienced occupancy-based dimming with a short fading time (close to 0 s) as acceptable. Even lower acceptance was experienced at desk 3, being 40-47% in *experiment 1* and 33-50% in *experiment 2*. When all workplaces were considered, both experiments showed, dimming with a fading time close to 2 s to be acceptable for more than 70% of the users. Looking at the desks separately, only desk 3 showed lower acceptance for dimming close to 2 s in *experiment 1*, being acceptance by on average 60% the users. Dimming with at least 5 s was found in both experiments, acceptable at all desks by more than 76% of the users. Acceptance ratings per desk of all conditions separately, are presented in Figure C.1 and Figure C.2 Appendix C.

In this study, co-workers' desks were subject to illuminance reductions of 7% up to 19%, with the highest reduction at the desk opposite to the fading luminaire. When reductions exceed these levels, or when co-workers positions have fading luminaires directly in their field of view, fading times should be considered cautiously to ensure user acceptance of light changes. Results of the most critical user positions shown in this study could then be considered (Figure C.1 and Figure C.2 Appendix C).

The task performed during the study was designed to avoid a constant focus on the screen (combining reading, thinking and writing). Participants were not restricted in their viewing directions and did not receive instructions to specifically look around during the task. Participants' actual viewing behaviour depended on the individual and was not captured. Instructing users to observe luminaires during the study is expected to negatively impact the acceptance of light changes.

In this study it was decided to block daylight by internal screens. By eliminating daylight influences, identical conditions could be tested in the different experimental sessions. As measured by Newsham and colleagues (Newsham, Mancini, et al., 2008), inclusion of daylight is expected to result in higher acceptance of all conditions. This could be caused by the already dynamic character of daylight, or due to larger perceptible steps of lighting at higher illuminance levels (NEN-EN 12464-1, 2011). Even though real offices do have daylight inclusion, situations with limited daylight, due to weather conditions, season, geographical location, or office design, need to be considered when specifying the dimming characteristics of the system.

5.4.2. Test conditions

The effect of dimming speed on the acceptance ratings was mainly due to the boundary of noticeability. Both experiments showed significant differences between the acceptance of fading in 0 and in 5 s. Most of the 5 s fading conditions were not noticed by the participants and therefore labelled with the highest acceptance value (8), while the conditions with close to 0 s fading were noticed by the participants and rated regarding their acceptance (1-7).

In both experiments, dimming direction did not show an effect on the acceptance ratings of light changes. This was evaluated by only considering the conditions without an occupancy change, to not include the activity of a person walking in or out, with or without a delay. In most conditions of both studies the dimming direction did not influence the noticeability of the light changes. Only dimming up with a fading time close to 0 s was noticed more often than dimming down with a fading time close to 0 s. This effect however was only present in *experiment 2*, not in *experiment 1*.

Only dimming up close to 0 s in *experiment 2* showed a significant effect of occupancy change on acceptance ratings, with the condition without an occupancy change being evaluated lower in acceptance than the dimming up close to 0 s with an occupancy change condition. In both experiments, occupancy changes did not have a significant effect on the noticeability of dimming. In *experiment 2*, dimming up in 0 s also resulted in a higher score on acceptance when linked to an occupancy change compared to not being linked to an occupancy change. Dimming down in 0 s did not show this effect. This might be due to the relatively long delay between the moment the actor left the workplace and the light change (5 min), causing participants to not experience the two events as correlated. This effect was however not found in *experiment 1*, where occupancy change was evaluated without the delay as well.

In *experiment 1* dimming down accompanied with an occupancy change was evaluated with and without a delay after the user left the office. Comparing these conditions, acceptance of dimming was higher when applied without a time delay after the user leaves his desk, which corresponds to the findings of Akashi and Neches (2005), reporting that feedback regarding the occurred change could enhance the acceptance of the users. In today's systems, delays are implemented to limit the risk of false negative detections. False negative detections could create dissatisfying situations when lighting is dimmed while a person is still present. When applying more advanced sensors with limited risk of false negatives, it is advised to dim lighting without the delay.

The acceptance ratings of dimming differed when participants were informed about the potential occurrence of light changes at the end of *experiment 1*. However, this was only significant when dimming down in five seconds as participants were more aware and vigilant of lighting changes. Regardless, acceptance ratings did remain within the positive part of the scale.

In the conditions with labels 13 and 14, the actors were asked to enter or leave the room without an accompanying light change. In both studies, none of the participants reported to have noticed a light change during these conditions. This supports the assumption that participants did not report a noticed light change in the experiment based on expectance of its occurrence but instead based on their actual observation. The standard EN12464-1 (2011) recommends a desk illuminance of 500 lx for office tasks (writing, typing, reading) and an illuminance of 300 lx for the immediate surrounding area. In this study dimming was limited to this range to achieve a situation that represents an actual office condition. This limited range could have impacted the outcome, as Krzyszczuk and Boyce (2002) report that each initial illuminance level has its own relative threshold value for detection of change. For an initial illuminance of 475 lx detection of change was after 22% dimming, and for 1095 lx this was after 17% dimming. Akashi and Neches (2004) reported that the probability of detection of illuminance reduction increases as the target illuminance decreases. In the latter study the increased illuminance delta was accompanied with an increasing speed which could have influenced the detection probability, due to the increase in perceptible steps with a larger dimming range (NEN-EN 12464-1, 2011). As such, the use of a more extreme range of dimming is therefore expected to influence the noticeability and acceptance of dimming.

Based on previous research, wall luminance and uniformity are expected to influence behaviour of users and perception of the space (Chraibi et al., 2017). In this study that influence is limited by using accent lighting spots to keep the wall illumination as constant as possible. Excluding the accent lighting is expected to increase the effect of dimming of luminaire L4 on the perceived scene brightness. Noticeability and acceptance ratings would than include the effects of changes in perceived scene brightness instead of limiting them to dimming conditions above a colleagues' desk.

5.4.3. Unnoticed occupancy changes

In *experiment 1* and *2*, only 229 of the 533 (43%) and 65 of the 136 (48%) occupancy changes were flagged by the participants. To not emphasize its occurrence, capturing occupancy changes was not mentioned explicitly during the verbal instructions. Occupancy was however shown in the on-screen list of potential changes during the introduction instructions. Participants were informed that different people could have different tasks during the experiment, to prevent participants leaving the office, when observing the actor to do so. In the informal conversations after the experiment, some participants indicated that they assumed entering and leaving the office was part of the task of that person and they did not always report this.

As with the occupancy changes, no time and order effects were found for the reported light changes presuming that participants did not become more focused nor indifferent on reporting noticed changes later in the experimental session. Even though the participants' attention was deviated from solely lighting, participants might still have been more focused on lighting, due to the location of the study (Philips office laboratory). In *experiment 1* and *2*, respectively 55 and 14 of the occupancy indications were registered as "other" but specified by the participants as an occupancy change. Even though mastering the English language was part of the inclusion criteria, it could be that some subjects were not familiar with the term "occupancy", influencing the indications provided. None of the participants however indicated during or after the experimental session to be unfamiliar with the term.

No significant effect was found for reporting of occupancy changes between the desks. Therefore, the workplace is not expected to have limited people from observing an occupancy change. A significant effect of desk was only found for the reporting of light changes, with the highest number of the light changes reported from the desk opposite the actor and the lowest number of from the desk diagonally opposite the actor. This is in line with the expected influence of dimming of luminaire 4 on the average illuminance of the desks. The unreported light changes are expected to be unnoticed by the participants, and not consequences of the study design.

5.5. Conclusions

This study evaluated the acceptance of occupancy triggered dimming of a single luminaire above a colleague's desk, in the users' visual field, for office workers. The luminaire was herein dimmed from an average of 310-345 lx to 543 lx horizontal desk illuminance, and vice versa. The conclusions of this research apply therefore to dimming between a minimum illuminance of 310 lx and a maximum illuminance of 543 lx.

This study showed co-worker's acceptance to increase with an increasing fading time for dimming. When dimming with a fading time close to zero (up to 0.27 s), less than 60% of the population rates the conditions as acceptable. However, by applying occupancy-based dimming on desk level while using a fading time of at least 1.71 s, an overall acceptance of at least 70% can be achieved, which is comparable to the level reported by Akashi and Boyce (2006) for users' satisfaction in a typical office in the US with static lighting.

Most evaluated conditions did not show an effect of co-workers visually observing a person triggering the change by entering or leaving the office space, on the acceptance levels. However, fast dimming up (822 lx/s) from 345 to 543 lx, did show an effect, being rated significantly higher in acceptance when co-workers could link the event to a person entering the office compared to no change in occupancy.

These results regarding acceptance levels apply to both examined age categories. Noticeability did show some difference between the age groups. Dimming with a fading time of 4.86 s or higher was not noticed by at least 80% of the population with a typical office age, while the examined student population showed a slightly more critical noticeability threshold, of 75% of the students not noticing the change when lighting was dimmed with a fading time of 4.86 s.

The results of the noticeability and acceptance of light changes are to be interpreted as an average for the entire office space. At some desks in the office space lower acceptance could be experienced. When co-workers have dimming luminaires directly in their visual field, or when co-workers’ desks are close to the dimming luminaire, resulting in large illuminance reductions due to lighting spill-over, acceptance ratings could be lower than evaluated in the rest of the office space. Fading times should therefore be considered carefully to avoid discomfort.

For the illuminance levels studied, in both experiments, acceptance of dimming up with 45 lx/s was found to be significantly higher than dimming up with 822 lx/s. Both when accompanied by an occupancy change as well as when applied without a change in occupancy. Without a change in occupancy, acceptance of dimming up in 133 lx/s was rated significantly higher than dimming up in 822 lx/s, in both experiments. Dimming down in 605 lx/s was rated significantly lower in acceptance than 45 lx/s, in both experiments, and lower than 22 lx/s, in *experiment 1.* Both when accompanied with an occupancy change as well as when applied without a change in occupancy.

Chapter 6

6. Discussion

6.1. Introduction

When offering lighting close to people's own preferences, a significant improvement in ratings of mood, lighting satisfaction and environmental satisfaction can be established. In multi-user office spaces, serving the individual with his or her preferred lighting is however challenging. With general lighting designed and applied at space level, the one-on-one relationship between the user and a luminaire is often absent. Even when control devices are offered on an individual basis, the controllable lighting is often shared, leading to consensus control. In this research, it was explored how to create satisfying lighting environments for the individual in these, nowadays widely applied, multi-user office spaces.

It was hypothesized that by offering personal control of shared lighting to users, the satisfaction of the individual office worker can be improved. The first study evaluated personal control in a field study in an open office environment. In a series of follow up studies different strategies to enhance the user satisfaction and limit the occurrence of conflict were explored, being: profiling of the user, the influence of the wall luminance in the users' visual field, and the influence of fading time of dimming.

In this Chapter, the key findings of this research are presented (Section 6.2). By evaluating the methodology used and acknowledging the strengths and limitations of the performed experiments, the significance of the results of this research is explained (Section 6.3). The results are discussed in the contextual environment of the office application (Section 6.4) and this Chapter ends with recommendations for future work (Section 6.5).

6.2. Key findings of this research

Improvements regarding parameters contributing to the wellbeing of office employees can be realised by offering satisfying lighting. Key findings of this research are:

In shared office spaces, like open plan offices, personal control over lighting can improve the users' appreciation of office lighting.

Even though in the field study controllable lighting was shared with colleagues in the same control zone, consensus control resulted in slightly higher satisfaction compared to situations with a fixed average work plane illuminance of 500 lx without control. This study demonstrated that, when offered controls, users' satisfaction with the amount of light on their desk and PC screen was rated just right, compared to experiencing a bit too much light in the fixed lighting conditions. The small difference showed to be statistically significant with a large effect size (following guidelines of Cohen (1988), with 0.1=small effect, 0.3=moderate effect, and 0.5=large effect). Light quality ratings also showed a small but significant improvement in the situations with control, compared to neutral ratings in the fixed lighting situations. When offered light controls, the users' average preferred illuminance values were shown to be 160 lx lower than in conditions with fixed 500 lx work plane lighting, resulting in 27.2% lower energy usage by lighting in the testbed of this study. Consensus control did not introduce a negative effect on the environmental satisfaction or the mood of the office users.

Based on users' control behaviour with the lighting system and zone luminaire output data, users can be profiled regarding their activeness, tolerance, dominance and lighting preferences. The ability to offer lighting conditions that meet the preference profiles of the users, creates the opportunity to improve users' satisfaction with lighting conditions.

The study showed that, based on the assigned user profiles in the control zones, zones can be classified to predict the probability of conflict occurring. A semi-automatic system that proposes lighting conditions by using lighting preference profiles can support users in finding consensus in addition to the benefits of manual personal control. A proposed illuminance level could be the result of a weighted combination of user profiles, considering the tolerance of the users. A tolerant user can be satisfied with a broad range of illuminance levels and therefore, the proposed illuminance level could be weighted towards the preference of the intolerant user. In flex offices (without assigned desks), users can be guided to zones that match their profiles. Zones are than defined by their daylight and electric lighting conditions, as well as by the other users of that zone.

With high average luminance levels of the wall in the users' visual field, the luminance and uniformity distributions influence the selected preferred task illuminance of users.

The results of this study indicate that, when provided with controls, users do not only select the lighting required for their visual task but also incorporate the observance of their visual field in their selected preference. The results indicate that high maximum luminance values of the wall in the visual field (600 cd/m^2 in this study) and subsequently high perceived brightness levels, lead to lower selected desk illuminance levels. The results also indicate that high minimum luminance values of the wall in the visual field (> 94 cd/m^2 in this study), creating less contrast between the task and the background, lead to higher selected desk illuminance levels.

The anchor of dimming (initial setting before adjustment) has a significant influence on users' selected task illuminances.

Offering users of open offices personal control with a 300-lx start level (anchor) to control their desk illuminance, instead of the recommended 500 lx, resulted in 26% lower selected preferred illuminances. Triggering lower selected illuminances, leads to lower energy used for lighting. An anchor of 300 lx (average desk level) has the potential to reduce the risk of conflict between people due to a smaller difference in preferred illuminances between users. However, this research does not answer whether these smaller differences are also perceivable by users.

A distinction can be made between noticeability and acceptance of light changes. Dimming from an average horizontal desk illuminance of just over 300 lx to well over 500 lx (or vice versa), increases the co-worker's acceptance with an incrementing fading time for dimming.

In the field study, light changes due to personal control were regularly noticed by co-workers in the space but rarely rated as disturbing. However, the noticeability did influence users in their choice to adapt the light. The laboratory experiments showed dimming with a fading time close to zero (< 0.3 s) leads to less than 60% of the participants rating the condition as acceptable. Applying occupancy-based dimming at desk level while using a fading time of at least 1.71 s, an acceptance of at least 70% can be achieved. This is comparable to the level reported by Akashi and Boyce (2006) for users' satisfaction in a typical office in the US with static lighting. Dimming with a fading time of 4.86 s or higher will not be noticed by at least 80% of the participants with a typical office age. The study showed no significant effect of dimming direction on the acceptance levels of the co-workers. In most conditions, the human trigger of a light change (a person entering or leaving the office space), did not show an effect on participants' acceptance levels. All results apply only for dimming in the examined range, from 310-345 lx to 543 lx horizontal desk illuminance or vice versa.

6.3. Strengths and limitations of this research

In this section, the experimental environment in which the studies in this research were conducted will be discussed. The discussion is based on the designed and selected context of the studies as well as on the tools used for evaluation.

6.3.1. Context of the studies

Testbed

The experiments conducted in this research were executed in two different spaces: an actual open office space (the field studies described in Chapter 2 and 3) and a simulated office space (the laboratory experiments described in Chapter 4 and 5).

Literature provides extensive reasons to believe that introducing personal control in the open office improves the satisfaction of the users. Even when conditions without control are not pronounced as 'uncomfortable', improvements in the user experience can be made. It is, however, a challenge to capture the difference between two lighting conditions that are both not perceived as 'uncomfortable'. This challenge is considered in this research by designing the experiment as a longitudinal field study. Running the evaluation of personal control as a *field study*, had the advantage of including the daily office characteristics in the use and judgement of personal control by users. These characteristics include, for example, the impact of the performed tasks and the user's exposure to verbal and non-verbal interactions with colleagues sharing the space. By designing the evaluation as a *longitudinal* field study, user experiences could be collected on various moments in time, anticipating a small, but positive, shift in user satisfaction. The longitudinal design of the evaluation also allowed for participants to unconsciously discover their individual lighting preferences as well as their preference as part of a group. Personal control could thus be evaluated in a context as close as possible to a real application. Limitations of a field evaluation are, however, the many uncontrolled variables in the office that could influence the evaluation parameters. The risk of confounding variables was lowered by designing the study as a longitudinal evaluation, measuring objective contextual parameters, including their subjective ratings, as well as counterbalancing the conditions.

Choices for system behaviour had to be made to maintain a balance between the conditions to be evaluated in the field studies and the burden on the participants. The burden on the participants can possibly influence the quality of the subjective data. Demanding too much from the participants creates the risk of losing their engagement, leading to incomplete data, or even participant dropout.

To extend the insights from the field study (Chapter 2) and allow for evaluation of multiple conditions within an acceptable time frame, the wall brightness and dimming speed explorations were evaluated in laboratory experiments (Chapter 4 and 5). In these laboratory experiments, variables expected to be of influence were controlled more systematically.

Task

The type of visual task performed by the participants during the evaluations, is expected to have an influence on the evaluation of the experienced discomfort (Kent, Fotios, & Altomonte, 2018). This influence might be assigned to the degree of cognitive attention required for the task and the ability to maintain fixation or reduce glances to the surroundings. In the experiments, participants performed either their actual office task (field studies) or a simulated office task (laboratory studies). Discomfort experiences and ratings reported in this research are expected to be lower than when a simple fixation task would have been used, due to the greater cognitive attention required for the tasks performed in this research. This greater cognitive attention could make people experience details in their environment to a lesser extent. The tasks used in this research are however more representative of real office tasks conducted in actual offices.

View and daylight

Daylight and view accompany each other almost always in offices. Al Horr et al. (2016) identified daylight and view as part of the physical factors of the building, affecting occupant satisfaction in an office environment. In the laboratory experiments, evaluating dimming speed and the influence of wall brightness, daylight contribution as well as view were removed by closing the internal window screens. Eliminating daylight influences allows for the creation of identical conditions during the different experimental sessions of a study. As shown by Newsham and colleagues (2008), inclusion of daylight is expected to result in higher acceptance of light changes. This could be caused by the already dynamic character of daylight, by the larger perceptible steps of lighting at higher illuminance levels (NEN-EN 12464-1, 2011), or due to the distraction by the view that often comes with the daylight opening. Higher luminance levels due to daylight entry are expected to lower the noticeability of electric light changes. It could be stated that the conditions tested in the laboratory experiments of this study represent the more critical situations with limited daylight. Situations with limited daylight could exist in actual office applications when screens or blinds are closed, or due to weather conditions, season, geographical location, or the office design.

In the field studies, described in Chapter 2 and 3, daylight entrance and view were not removed. The office used for the field studies had large windows. By having enough light available due to daylight, users may have felt less inclined to control the artificial lighting. In both experiments, blinds were closed frequently by the participants to control heat or limit the experience of glare due to direct sunlight or a bright sky. The testbed was located on the fourth floor and its view included different layers of green, a lake, and a part of the highway (covered by foliage depending on the season). In interviews, some participants did express to consider maintaining their view as much as possible when selecting the position of the internal or external blinds. A pleasant view is expected to positively influence people's tolerance of discomfort (Aries et al., 2010). This is coherent with studies showing that observers become more tolerant to discomfort due to glare when the glare source (daylit window) contains pleasant information (Tuaycharoen & Tregenza, 2005, 2007). In these studies, views including natural scenes were reported as less glaring than images of urban scenes, with additional positive contributions for the presence of water. In the research of Matusiak and Klöckner (2016) however, the extent of greenery in the view and the presence of water showed not to additionally contribute to the perceived view quality. Increased tolerance of the office conditions, due to a pleasant view, could affect control behaviour of users or affect their satisfaction with lighting through control actions of others. This could impact the risk of conflict occurring (Figure 12, Chapter 3).

Lighting control

In the field studies, user control was offered by means of a vertical slider on a personal smart device (see Figure 5 Chapter 2, Figure 3 Chapter 3). By using the slider, users could control the lighting in their assigned control zone. Fotios and Cheal (2010) suggested that illuminance adjustments are characterised by a centring bias, with mean preferred illuminances tending to lie near the centre of the available stimulus range. This centring bias was not revealed in the performed field study. In the first field study (Chapter 2), the controllable luminaires were set by the users on maximum output for 41% of the time and below a 60%-dimming level for 56% of the time (Figure 8, Chapter 2). This centring bias was also not revealed in the wall brightness experiment (Figure 7, Chapter 4).

In the field study, the controllable luminaires were adjustable in a range from 1 to 100% luminaire output, delivering a maximum average desk illuminance of 500 lx by artificial light only. Offering a different range is expected to influence the users' expressed preferred illuminance, as already shown in multiple previous studies (Fotios & Cheal, 2010; Logadottir et al., 2011a). Even though absolute preferred illuminance values are expected to deviate, a variation of preferences between users is expected to hold (Boyce et al., 2006b; Newsham, Veitch, Arsenault, & Duval, 2004c; Veitch & Newsham, 2000b).

When the user-control condition was introduced in the field study, the controllers were set at an anchor point of 60%. This anchor point is the initial setting before adjustment, also referred to as starting point. Users were not specifically informed about the range or anchor of the controller. In the interviews, it appeared that some users assumed the anchor point to resemble the previous setting of the no-control condition. They indicated to be pleased with the extended range they were given by the introduction of controls. As shown in previous studies, the anchor is expected to have influenced the users' selected preference (Fotios & Cheal, 2010; Logadottir et al., 2011a; Uttley et al., 2013). A lower anchor is for example expected to lead to lower selected levels. In the experiment evaluating the influence of wall brightness, it was tried to exclude the effect of the given range and the anchor on the selection of preferred dimming levels. This was done by using a range and anchor without a visual reference in the design of the interface and including three different anchors is the experimental design. Even though no visual reference was given, the study showed the anchor to have a significant effect on the selected levels, with lower levels selected when offering a low anchor and higher selected levels when offering a high anchor, in line with previous research (Fotios & Cheal, 2010; Uttley et al., 2013). The sequence of the three different anchors was however not randomized between conditions. Each condition was first evaluated from the default dimming start position (500 lx desk level), followed by the minimum (ca. 300 lx) and the maximum (ca. 700 lx) start position, before continuing to the next condition. Users could have been biased by the order of these conditions (Kent, Cheung, Altomonte, Schiavon, & Lipczyńska, 2018). During the conversations after the experiment, users however shared not to have noticed a difference between a new condition or the same condition with a different start position, for them all were "new" conditions. In this study, the visual representation of the range was excluded from the design of the interface. When provided with a visual scale, users may be inclined to re-apply an earlier decided setting rather than make a new evaluation.

Due to the influence of the range and anchor, the absolute values of the preferred illuminance found in this research should only be interpreted in the context of this study. Results from Uttley et al. (2013) do underpin that even though the anchor point and range do influence the selected light level, they do not influence the satisfaction of the users with their light preference.

In the field studies, the controller included enough steps to offer a slider perceived as continuous, rather than step-wise. When control actions were performed, lighting was adjusted with a dimming speed of two seconds, using a linear dimming curve. A dimming command was sent to the system only after the user released his or her finger from the slider. This was to avoid the system from crashing due to a command overload. Users indicated small, slow, or gradual light changes to be more acceptable and generally not perceived as negative by the observer, while fast and large light changes were less appreciated. Participants of the field studies shared in the interviews that they used strategies to make light changes, to avoid that colleagues present in the office would notice their actions. They would make changes when their neighbours were not present yet or not around, or to make light changes by moving the slider relatively slow or in multiple small steps (Lashina et al., 2019). Fast noticeable changes were accompanied by neutral remarks by co-workers that still fed a hesitation to use the controls. This is in line with feedback received from users in an evaluation performed in a Dutch office building deployed with personal control (Smiggels, 2017). Users in that study stated to hesitate to use the application on their smart phone for the control of the lighting, due to changes being clearly noticeable by others in the office space. The users made a comparison with the less noticeable temperature adjustments, which are more gradual in their output and therefore easier controlled by the users.

6.3.2. Evaluation tools

Informing subjects on objective

In the performed evaluations, participants were not informed about the objective of the study. Informing participants prior to the experiment might lead to biased evaluations and behaviour, creating a situation which does not represent an actual office situation. In the study performed by Veitch et al. (2010), an informed awareness campaign, reminding people of the controls through an email, led to more active use of the controls. In that study, the increased awareness of controls led to a tendency of higher selected light levels, but did not improve occupant satisfaction, which could be due to already high satisfaction levels. In the performed field studies, the purpose of the study as presented to the participants was kept as broad as ‘their office experience including aspects such as temperature, air quality, lighting, and noise’. In the dimming speed evaluation study, conditions were evaluated without and with informing participants. The noticeability of dimming was expected to be higher and acceptance to be lower when users would be informed and made aware of light changes happening. The results however showed that informing participants had no significant effect on the ratings of all, but one condition. Only during the condition in which dimming up in five seconds was evaluated, change was noticed significantly more often and rated slightly lower in acceptance when participants were informed on the possibility of light changes occurring (improving from an average rating of ‘acceptable’ when informed to ‘very acceptable’ when uninformed).

Subjective data

Küller et al. (2006) highlighted in their research the importance of subjective assessments of lighting. In this research, subjective assessments are collected through surveys and interviews. Especially in longitudinal field evaluations, the collection of subjective data introduces challenges. The risk of missing data or drop out of participants is high. In the performed experiments, this risk is attempted to be reduced by limiting the burden on the participants and creating and maintaining engagement of the participant group.

In both field studies, subjective data was collected via short weekly surveys as well as by extended surveys at the end of each condition and complemented with face-to-face interviews at the end of each condition. The participants were asked to fill in the surveys on their last work day of the week. Weekly reminders with the survey link were sent on a personally indicated suited time. When needed, on Monday mornings, a second reminder was sent. In case participants regularly forgot to fill in surveys, solutions were discussed during the interviews. This approach resulted in high commitment and very limited missing data. This strategy is however very time consuming for the research team and almost impossible when considering a larger scale field evaluation.

Interviews were scheduled in private meeting rooms near the testbed. The interview data complemented the input given through the surveys, hence allowing to limit the length of the surveys. These periodical meetings also contributed in creating engagement of the participants. In preparation for the interviews, the user input over the preceding period was studied. Additional notes made in the surveys were discussed, and the opportunity was given to further elaborate on antecedent experiences. Participants shared in the interviews to appreciate the preparation by the researcher, since it disarmed the preconception of individual input in surveys not being read. In a few cases extended surveys were not filled in yet when interviews were planned, because participants did not had time yet or forgot to do so. Ample booked time gave them the opportunity to first fill in the survey (at their desk), prior to the interview. This was appreciated by the participants.

Prior to the start of the study, an informative group session was scheduled to inform participants on the relevancy of user research in general, and the value of their commitment as a group. Complying with the ethics guidelines of the organization, participants were also informed that they could always terminate their participation without any consequences. To inform participants about the duration of the study, the planning of the study was shared, which included a group lunch at the end of the study to celebrate a successful study closure and to share the (first) results.

Using face-to-face interactions to complement data and build personal engagement is more challenging or even impossible when conducting large scale studies or when test sites are distant. In these situations, advanced sensors could potentially provide additional information to complement the data. Extensive data sets of performed research, like the one presented here, could be used to explore the use of these technologies. In this study, all reminders were scheduled and send manually. With large user groups, automation of reminders on personalized suited moments could expand the input provided by the users.

6.4. Contextual environment – office application

This research showed that in shared office spaces, like open plan offices, personal control over lighting improved the users' appreciation of office lighting. By impacting the user's wellbeing, effectivity, and engagement, state-of-the-art smart lighting systems have the potential to play a role in addressing organizational productivity. To translate the results obtained in this research to insights valid for general open office environments, the results need to be interpreted carefully. In this Section, elements for consideration will be discussed.

System behaviour

In the first field study, personal control over lighting resulted in higher satisfaction of users with the quality of light as well as with the amount of light on the users' desk and PC screen, compared to a situation without user control. In this study, personal control was evaluated using a system with a "memorizing" behaviour. In this "memorizing" strategy, the user-selected diming level was remembered and restored every time the system was triggered by an occupancy sensor to switch on. To simplify the system behaviour, daylight harvesting (regulating artificial light levels by considering available daylight) was switched off after a first user action in a control zone and remained off for the remainder of the user control condition. In actual office applications, this might however not be an ideal system behaviour to implement. Consideration of energy efficiency when designing systems and their behaviour, is important, but outside the scope of this research. Current standards (Ashrae, 2016) prescribe using daylight regulation in new and renovated lighting installations to increase energy efficiency of modern buildings. A rising number of buildings already apply daylight harvesting as a standard lighting control strategy. Integrating daylight regulation when applying personal control in office buildings ("set-point controlled" system behaviour) or resetting the system daily to lower default dimming levels ("forgetting" system behaviour) could lead to lower energy usage by lighting. Lower default switch-on levels are expected to lead to lower luminaire output and energy consumption (Moore et al., 2002a). Besides the energy aspect, restoring desk dimming levels to a default value at given moments, e.g. at the start of every new day, makes sense when considering flex offices in which desks are not assigned to specific users. These flex office concepts are more frequently applied in today's office designs.

The "memorizing" behaviour remembers the users' set level and avoids situations in which users are required to unnecessarily repeatedly set their preference. Implementing personal control in offices with a system behaviour different than the evaluated "memorizing" behaviour could lead to lower satisfaction by users than observed in this research. However, comparing the "memorizing" behaviour with other personal control strategies in an explorative study did not show convincing user experience differences (Lashina et al., 2019).

Knowing the preference profile of a user, as proposed in Chapter 3, an advanced system for personal control can be considered, which integrates the user's preference regardless of the user being assigned to a fixed desk or having flexible work places. This "smart-memorizing" behaviour could be extended by considering available daylight and regulating dimming levels accordingly to optimize energy efficiency. Introducing automatic behaviour, it is important to properly inform users, to obtain a positive user experience. In the performed field study, changes of the light level that were not triggered by a user action, were described as confusing. Users could not easily understand why lighting was changing automatically just moments after a performed user action.

Dimming speed

In the experiments evaluating dimming speed in the laboratory office, testing of multiple conditions led to frequent changes in occupancy. In an actual office situation, changes due to occupancy might be less frequent than every 5 or 10 minutes (depending on the type of work). It is expected that in this study a more critical situation is evaluated where users were exposed to more frequent changes. In addition, during the performed laboratory experiments, simulated tasks were used, and the view of the participants was blocked by screens. Distractions from e.g., a view or a cognitively demanding task (Kent et al., 2018) are expected to lower the noticeability of light changes.

The laboratory experiments showed that at least 75% of the users did not notice a light change, when lighting was dimmed between 310 lx and 543 lx with a speed up to 45 lx/s. When controlling lighting by means of personal control, the noticeability of the change provided the user with direct feedback of the system receiving the command and processing the expressed preference. Noticeable light changes caused by interactions by other people were also shown to serve as a strong trigger for users to use the controls (Niemantsverdriet, 2018), by reminding them to consider the possible benefit of the light controls. It is therefore suggested to apply personal control triggered dimming between the boundaries of noticeable and acceptable light changes, being faster than 45 lx/s for noticeability and up to 133 lx/s for acceptance by at least 70% of the users. The results relate to the desk illuminance range between 310 lx and 543 lx. The dimming speed may need to be adjusted when a larger illuminance range or dimming start points outside the currently tested range are applied.

Flex office

In the performed field studies, personal control was evaluated in an office in which each user was assigned to a dedicated desk. The participant group was already familiar with each other and with sharing an office. This is expected to impact the potential of experienced conflict by feeling less inhibited to perform actions, compared to not knowing neighbours (Lashina et al., 2019). Following trends like New Ways of Working (Leesman, 2016), offices more frequently are designed as flex offices, in which desks do not have one returning user. New office concepts, in which users can rent a desk for a day, introduce not only a different, but also an unknown neighbour.

Even though users are expected to consider their co-workers when making a change (Niemantsverdriet, Broekhuijsen, Van Essen, & Eggen, 2016), in this research, users shared in the interviews to not discuss their lighting preferences with their neighbours. Literature shows that even dominant individuals avoid open discussion regarding preferences with colleagues and do not proactively search consensus (Lashina et al., 2019). Yet, some users did share to know the preference of their neighbours, through multiple observations of their neighbours' performed actions. In offices with changing neighbours this is more challenging. Smart systems could contribute here by using the user interface to discretely inform users of the preferences of their (unknown) neighbours. Alternatively, when users' preference profiles are known (Chapter 3), a smart semi-automatic system could consider users and propose or automatically control lighting. These semi-automatic systems could support users in finding consensus in addition to the benefits of manual personal control. A proposed illuminance level could result from a weighted combination of user profiles by considering the tolerance levels of the users present in the same zone. When user preference profiles are known, users could also be guided by the interface to workplaces that match their profiles.

Interfacing with shared systems

Offering users a local control has been shown to lead to lower selected dimming levels than when controls are distant (e.g. wall mounted) (Moore et al., 2002a). Applying connected lighting systems, with control through network communication, allows for offering light control on personal devices without extensive hardware investments. This could be by a dedicated smart phone application or as a feature in a comprehensive building control or services application. The usability and ease of use of the application comprising the controls will have a direct impact on the frequency of use (Sadeghi et al., 2016). To be able to apply the results obtained in this research to connected lighting systems using smart phone applications, personal control was evaluated using personal smart devices, i.e. an iPod touch generation 5. Even though this control device is personal, the lighting system to interact with is shared. The study of Niemantsverdriet (2018) underpinned that the perceived shared nature of the lighting system influences the way people interact with the system. Users seem to consider the other people present in the office in almost every interaction performed and, as shown by Lashina et al. (2019), also when avoiding conflict by not performing interactions. The study of Niemantsverdriet (2018), shares three considerations mentioned by users during their interactions with the shared system are 1) the individual's reason to interact, 2) the expected impact their action will have on others, and 3) how to balance own concerns and the concerns of others. The interface can provide users with information to increase their awareness of the social context. Including awareness information in the design of the interface of the shared lighting system, is expected to lead to more collaborative ways of interacting. Providing users with additional information, should however be done such that it does negatively influence the users' productivity.

The personal control interface, used in the field studies of this research, was evaluated by the participants as 'very easy to use'. The effort and complexity of interaction has been shown to influence people's behaviour (Escuyer & Fontoynont, 2001; Sadeghi et al., 2016; Van de Werff, Niemantsverdriet, Van Essen, & Eggen, 2017). In a study evaluating personal control in a large Dutch office building, the light controlling feature was rated by the users as 'easy to use' (Smiggels, 2017). Controlling lighting was however challenging because of difficulties the user was facing before reaching the lighting control slider. When implementing digital interfaces, some essential user experience elements need to be considered. With traditional wall mounted switches, users are experienced and trained to find the controls, which are often located near the entrance of a space. When offering controls through digital channels, the logic of finding the controls should be of similar simplicity to not create challenges for using the controls. In the earlier mentioned Dutch office building, users had to self-install the lighting application on their smart-phones, but experienced challenges in finding it. Simple things like the name of the application become essential in user's access to lighting control. System and data security as well as privacy are currently hot topics and networked services are often run on secured company networks. When the lighting system makes use of this secured network, users need to be connected to the internal company network for controlling lighting. As much as this might sound logical for the engineer of the system, for many users this might not be the case. Providing the right information at correct moments or via correct channels is the key for a successful application of lighting control using personal smart devices. Not only right after implementation of a smart system in a building, but also for users moving into the building later in time. Connected systems provide numerous opportunities to enhance the user experience in offices. When offering controls, the (simple and logical) potential of digital interfaces must be used to its full extent to provide users with easy interaction tools for these complex systems.

6.5. Recommendations for future work

In this thesis, personal control was examined as a means to improve individual satisfaction in multi-user office spaces. Even though personal control was found to improve the users' satisfaction with lighting, cases of conflict were still observed. As part of this research a selection of strategies have been explored to limit experiencing conflict and optimize the personal control proposition. The selected strategies are not all-inclusive but are selected for this research based on their importance, business applicability, and feasibility. These explored strategies comprise; profiling of users based on control behaviour, the influence of wall brightness on performed actions, and the influence of dimming speed on noticeability and acceptance of light changes.

Although the research resulted in many valuable insights (Section 6.2), there are several limitations, as discussed in Section 6.3. Based on these limitations, recommendations for future research are provided below.

The research focussed on the open office environment, as today widely applied in modern European offices. An open office in a Dutch office building was used for the field study, which formed the basis of this research. This was an office space, offering up to 16 workplaces, enclosed by two walls, two small break-out rooms, and a large window (Figure 1, Chapter 2). Open offices, however, could also be applied in a much larger scale, in which the visual field of the user contains a larger portion of the ceiling. This could impact the noticeability of light changes or provide different light settings in the space. In North American offices, partitioning is often used between desks or groups of desks. Besides its influence on the distribution of lighting, partitioning impacts the perception of sharing of the lighting system by users as well as the communication between users. To confirm the applicability of the results, a validation should be done in open offices with a different type, design, or scale. Furthermore, offices with users from different global cultures should be considered. The culture could potentially affect the perception of personal or sharing of the office and the lighting system.

In this research, strategies that could potentially influence energy consumption are discussed, for example the use of low anchors that lead to lower selected desk illuminance values. Lower desk illuminance values often also impact light levels at the user's eyes. In future research, the impact of personal control on light at the eye should be considered, for its effects and consequences on the non-image forming effects of lighting.

The studies performed in this research were all done with settings specifically set up for the purpose of the research. This being either in a mock up office in the laboratory or in a field study in which multiple conditions were introduced. Users were aware of their participation in a study, which could have influenced their behaviour and experience, even though exact objectives were not shared. This research could be extended by a post occupancy evaluation of personal control, in which controls have been used for a longer amount of time by office employees. It also allows for inclusion of a larger participant group. However, other means for collecting user experience data should then be considered. As already discussed earlier, creating and maintaining engagement via strategies as used in this research will be challenging in larger groups.

In this research wellbeing is assessed through users' satisfaction with light quantity and quality, mood, conflict experience, lighting preference and acceptance ratings of light changes. These components are believed to contribute to wellbeing but provide a partial view of the complexity that is featured within the concept of wellbeing in buildings. Further investigation of how to assess user wellbeing in offices on all relevant axes, while limiting the effort required from the users, is found relevant.

It is suggested to integrate subjective system evaluations in the lighting control application. This should however be integrated such that it does not harm the ease of use and usability of the control device. A second suggestion is to include evaluations of building features and services in organizations' periodical surveys, which are often distributed through human resources departments. Combining these data sets offers opportunities of quantifying the benefits of satisfying lighting in organizational productivity metrics, as employee engagement scores, or even absenteeism. Evidence based claims of the impact of lighting will benefit the application of lighting, not only as a functional element of the office environment, but also a contributor to healthy, happy, and comfortable employees.

References

References

aan het Rot, M., Moskowitz, D. S., & Young, S. N. (2008). Exposure to bright light is associated with positive social interaction and good mood over short time periods: A naturalistic study in mildly seasonal people. *Journal of Psychiatric Research*, *42*(4), 311–319. https://doi.org/10.1016/j.jpsychires.2006.11.010

Aghemo, C., Blaso, L., & Pellegrino, A. (2014). Building automation and control systems : A case study to evaluate the energy and environmental performances of a lighting control system in offices. *Automation in Construction*, *43*, 10–22. https://doi.org/10.1016/j.autcon.2014.02.015

Akashah, F. W., Ali, A. S., & Zahari, S. F. M. (2015). Post-occupancy evaluation (POE) of conventional-designed buildings: The effects of occuapnts' comfort on productivity. *Jurnal Teknologi*, *75*(1), 27–37. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-84933523655&partnerID=40&md5=3ee83924c90a6633c020e630894644a8

Akashi, Y., & Boyce, P. R. (2006). A field study of illuminance reduction. *Energy and Buildings*, *38*(6), 588–599. https://doi.org/10.1016/j.enbuild.2005.09.005

Akashi, Y., & Neches, J. (2004). Detectability and Acceptability of Illuminance Reduction for Load Shedding. *Journal of the Illuminating Engineering Society*, *33*(1), 3–13. https://doi.org/10.1080/00994480.2004.10748422

Akashi, Y., & Neches, J. (2005). Potential recommendations for illuminance reductions by load-shedding. *Lighting Research and Technology*, *2*(37), 133–153.

Al Horr, Y., Arif, M., Kaushik, A., Mazroei, A., Katafygiotou, M., & Elsarrag, E. (2016). Occupant productivity and office indoor environment quality: A review of the literature. *Building and Environment*, *105*, 369–389. https://doi.org/10.1016/j.buildenv.2016.06.001

Altomonte, S. (2009). Daylight and the occupant: Visual and physio-psychological well-being in built environments. In *PLEA 2009 - Architecture Energy and the Occupant's Perspective: Proceedings of the 26th International Conference on Passive and Low Energy Architecture*. Institute of Architecture, School of the Built Environment, University of Nottingham, United Kingdom. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-84855605150&partnerID=40&md5=c1c1fa417c712b16f789fc86c9b0fca4

Appel-Meulenbroek, R., Kemperman, A., van Susante, P., & Hoendervanger, J. G. (2015). Difference in employee satisfaction in new versus traditional work environments. In *14th EuroFM Research Symposium* (pp. 1–10).

Aries, M. B. C., Veitch, J. A., & Newsham, G. R. (2010). Windows, view, and office characteristics predict physical and psychological discomfort. *Journal of Environmental Psychology*, *30*(4), 533–541. https://doi.org/10.1016/j.jenvp.2009.12.004

Ashrae. ASHRAE STANDARD 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings, 8400 Society § (2016). https://doi.org/http://dx.doi.org/10.1108/17506200710779521

Baird, G., Thompson, J., & Marriage, G. (2010). Lighting conditions in sustainable buildings: Results of a survey of users perceptions. *44th Annual Conference of the Architectural Science Association*.

https://doi.org/10.1080/00038628.2012.667941

Baričič, A., & Salaj, A. T. (2014). The impact of office workspace on the satisfaction of employees and their overall health - Research presentation. *Zdravniski Vestnik*, *83*(3), 217–231. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-84897406717&partnerID=40&md5=ae17c0e3af9231ac5d6e7687761472cf

Barlow, S., & Fiala, D. (2007). Occupant comfort in UK offices—How adaptive comfort theories might influence future low energy office refurbishment strategies. *Energy and Buildings*, *39*(7), 837–846. https://doi.org/10.1016/j.enbuild.2007.02.002

Baron, R. A., Rea, M. S., & Daniels, S. G. (1992). Effects of indoor lighting (illuminance and spectral distribution) on the performance of cognitive tasks and interpersonal behaviors: The potential mediating role of positive affect. *Motivation and Emotion*, *16*(1), 1–33. https://doi.org/10.1007/BF00996485

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*(3), 231–239. https://doi.org/10.1016/S0169-8141(96)00053-4

Bergs, J. (2002). The Effect of Healthy Workplaces on the Well-being and Productivity of Office Workers. *International Plants for People Symposium*, 1–12.

Berrutto, V., Fontoynont, M., & Avouac-Bastie, P. (1997). Importance of wall luminance on users satisfaction: pilot study on 73 office workers. In *Proceedings of Lux Europa - 8th European Lighting Conference 1997* (pp. 82–101).

Bluyssen, P. M., Aries, M. B. C., & van Dommelen, P. (2011). Comfort of workers in office buildings: The European HOPE project. *Building and Environment*, *46*(1), 280–288. https://doi.org/10.1016/j.buildenv.2010.07.024

Bordass, B., Bromley, K., & Leaman, A. (1993). User and Occupant Controls in Office Buildings. *International Conference on Building Design, Technology and Occupant Well-Being in Temperate Climates*, (February), 12–15.

Borisuit, A., Linhart, F., Scartezzini, J. L., & Münch, M. (2015). Effects of realistic office daylighting and electric lighting conditions on visual comfort, alertness and mood. *Lighting Research and Technology*, *47*, 192–209. https://doi.org/10.1177/1477153514531518

Boubekri, M., Cheung, I. N., Reid, K. J., Wang, C. H., & Zee, P. C. (2014). Impact of windows and daylight exposure on overall health and sleep quality of office workers: A case-control pilot study. *Journal of Clinical Sleep Medicine*, *10*(6), 603–611.

Boyce, P. R. (2003). *Human Factors in Lighting*. (L. R. Center, Ed.) (2nd ed.). Londen and New York: Taylor and Francis group.

Boyce, P. R., & Cuttle, C. (1990). Effect of correlated colour temperature on the perception of interiors and colour discrimination performance. *Lighting Research and Technology*, *22*(1), 19–36. https://doi.org/10.1177/096032719002200102

Boyce, P. R., Eklund, N. H., & Simpson, N. S. (2000). Individual Lighting Control: Task Performance, Mood, and Illuminance. *Journal of Illuminating Engineering Society*, 131–142.

Boyce, P. R., Hunter, C., & Howlett, O. (2003). The Benefits of Daylight through Windows Sponsored by: Capturing the Daylight Dividend Program The Benefits of Daylight through Windows, 1–88.

Boyce, P. R., Veitch, J. A., Myer, M., & Hunter, C. M. (2003). *Lighting Quality and Office Work: A Field Simulation Study. PNNL*.

Boyce, P. R., Veitch, J. A., Newsham, G. R., Jones, C. C., Heerwagen, J. H., Myer, M., & Hunter, C. M. (2006a). Lighting quality and office work: two field simulation experiments. *Lighting Research and Technology*, *38*(3), 191–223. https://doi.org/10.1191/1365782806lrt161oa

Boyce, P. R., Veitch, J. A., Newsham, G. R., Jones, C. C., Heerwagen, J. H., Myer, M., & Hunter, C. M. (2006b). Occupant use of switching and dimming controls in offices. *Lighting Research and Technology*, *38*(4), 358–378. https://doi.org/10.1177/1477153506070994

Cajochen, C. (2007). Alerting effects of light. *Sleep Medicine Reviews*, *11*(6), 453–464. https://doi.org/10.1016/j.smrv.2007.07.009

Carter, D. J., Slater, A. I., Perry, M. J., Mansfield, K. P., Loe, D. L., & Sandoval, J. (1994a). The influence of luminance distributions on subjective impressions and performance within a non-uniformly lit office. In *CIBSE National lighting conference* (pp. 61–74).

Carter, D. J., Slater, A. I., Perry, M. J., Mansfield, K. P., Loe, D. L., & Sandoval, J. (1994b). The influence of wall luminance distribution on subjective impressions and performance within a non-uniformly lit office. In *CIBSE National Lighting Conference* (pp. 61–74).

Cetegen, D., Veitch, J. A., & Newsham, G. R. (2008). View Size and Office Illuminance Effects on Employee Satisfaction. *Proceedings of Balkan Light*. Retrieved from http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc50852/nrcc50852.pdf

Choi, J. H., & Moon, J. (2017). Impacts of human and spatial factors on user satisfaction in office environments. *Building and Environment*, *114*, 23–35. https://doi.org/10.1016/j.buildenv.2016.12.003

Chraibi, S., Crommentuijn, L., van Loenen, E. J., & Rosemann, A. L. P. (2017). Influence of wall luminance and uniformity on preferred task illuminance. *Building and Environment*, *117*, 24–35. https://doi.org/10.1016/j.buildenv.2017.02.026

Chraibi, S., Lashina, T. A., Shrubsole, P., Aries, M. B. C., van Loenen, E. J., & Rosemann, A. L. P. (2016). Satisfying light conditions: A field study on perception of consensus light in Dutch open office environments. *Building and Environment*, *105*, 116–127. https://doi.org/10.1016/j.buildenv.2016.05.032

Dangol, R., Islam, M. S., Hyvarinen, M., Bhusal, P., Puolakka, M., Halonen, L., … Halonen, L. (2013). User acceptance studies for LED office lighting: Preference, naturalness and colourfulness. *Lighting Research and Technology*, *0*, 1–18. https://doi.org/10.1177/1477153513514424

de Kort, Y. A. W., & Smolders, K. C. H. J. (2010). Effects of dynamic lighting on office workers: First results of a field study with monthly alternating settings. *Lighting Research and Technology*, *42*(3), 345–360. https://doi.org/10.1177/1477153510378150

de Vries, H. J. A., Heynderickx, I. E. J., de Kort, Y. A. W., & de Ruyter, B. (2015). Wall illumination – beyond room appraisal. In *Proceedings of 28th CIE Session* (pp. 284–290).

de Vries, H. J. A., Souman, J. L., de Ruyter, B., Heynderickx, I., & de Kort, Y. A. W. (2018). Lighting up the Office: The effect of wall luminance on office worker performance. *Building and Environment*, *142*(May), 534–543. https://doi.org/10.1016/j.buildenv.2018.06.046

de Vries, H. J. A., & Van der Vleuten-Chraibi, S. (2019). Creating engaging office environments - light for the heart, light for sight, light for the mind. *Signigy White Paper*, 1–16.

Despenic, M., Chraibi, S., Lashina, T. A., & Rosemann, A. L. P. (2017). Lighting preference profiles of users in an open office environment. *Building and Environment*, *116*, 89–107. https://doi.org/10.1016/j.buildenv.2017.01.033

Diener, E., & Emmons, R. A. (1984). The independence of positive and negative affect. *Journal of Personality and Social Psychology*, *47*, 1105–1117.

Duff, J., Kelly, K., & Cuttle, C. (2017). Perceived adequacy of illumination, spatial brightness, horizontal illuminance and mean room surface exitance in a small office. *Lighting Research and Technology*, *49*(2), 133–146. https://doi.org/10.1177/1477153515599189

Durak, A., Olgunturk, N. C., Yener, C., Guvenc, D., & Gurcinar, Y. (2007). Impact of lighting arrangements and illuminances on different impressions of a room. *Building and Environment*, *42*, 3476–3482. https://doi.org/10.1016/j.buildenv.2006.10.048

Easterbrook, S. M., Beck, E. E., Goodlet, J. S., Plowman, L., & Sharples, M. (1993). A Survey of Empirical Studies of Conflict. In *CSCW: Cooperation or Conflict?* (pp. 1–68).

Elzeyadi, I. (2011). Daylighting-Bias and Biophilia: Quantifying the Impact of Daylighting on Occupants Health. *Greenbuild 2011*, 1–9. Retrieved from http://www.usgbc.org/resources/daylighting-bias-and-biophilia

Enomoto, K., Kondo, Y., Obayashi, F., Iwakawa, M., Ishii, H., Shimoda, H., & Terano, M. (2008). An experimental study on improvement of office work productivity by circadian rhythm light. In *WMSCI 2008 - The 12th World Multi-Conference on Systemics, Cybernetics and Informatics, Jointly with the 14th International Conference on Information Systems Analysis and Synthesis, ISAS 2008 - Proc.* (Vol. 6, pp. 121–126). Kyoto University, Gokasho, Uji, Kyoto, 611-0011, Japan. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-76249119103&partnerID=40&md5=cb228f68cf67eb4169700e197725dcc5

Erickson, T., & Kellogg, W. A. (2000). Social Translucence: An Approach to Designing Systems that Support Social Processes. *ACM Transactions on Computer-Human Interaction*, *7*(1), 59–83.

Escuyer, S., & Fontoynont, M. (2001). Lighting controls: a field study of office workers' reactions. *Lighting Research and Technology*, *33*(2), 77–94. https://doi.org/10.1177/136578280103300202

Feige, A., Wallbaum, H., Janser, M., & Windlinger, L. (2013). Impact of sustainable office buildings on occupant's comfort and productivity. *Journal of Corporate Real Estate*, *15*(1), 7–34. https://doi.org/10.1108/JCRE-01-2013-0004

Field, A. (2009). *Discovering Statistics* (3rd ed.). SAGE Publications Ltd.

Figueiro, M. G., & Rea, M. S. (2014). Office lighting and personal light exposures in two seasons : Impact on sleep and mood. *Lighting Research & Technology*, *0*(3), 1–13. https://doi.org/10.1177/1477153514564098

Figueiro, M. G., Steverson, B., Heerwagen, J., Kampschroer, K., Hunter, C. M., Gonzales, K., … Rea, M. S. (2017). The impact of daytime light exposures on sleep and mood in office workers. *Sleep Health*, *3*(3), 204–215. https://doi.org/10.1016/j.sleh.2017.03.005

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 Lighting Conference Lux Europa 2001*, (June), 76–80. https://doi.org/10.3929/ethz-a-004362002

Fostervold, K. I., & Nersveen, J. (2008). Proportions of direct and indirect indoor lighting - The effect on health, well-being and cognitive performance of office workers. *Lighting Research and Technology*, *40*(3), 175–197. https://doi.org/10.1177/1477153508090917

Fotios, S. (2011). Lighting in offices: lamp spectrum and brightness Coloration Technology. *Coloration Technology*, *127*, 114–120. https://doi.org/10.1111/j.1478-4408.2011.00285.x

Fotios, S., & Cheal, C. (2010). Stimulus range bias explains the outcome of preferred-illuminance adjustments. *Lighting Research and Technology*, *42*(4), 433–447. https://doi.org/10.1177/1477153509356018

Fotios, S., Logadottir, A., Cheal, C., & Christoffersen, J. (2012). Using adjustment to define preferred illuminances: do the results have any value? *Light and Engineering*, *20*(2), 46–55.

Galasiu, A. D., Newsham, G. R., Suvagau, C., & Sander, D. M. (2007). Energy saving lighting control systems for open-plan offices: a field study. *LEUKOS - Journal of Illuminating Engineering Society of North America*, *4*(1), 7–29. https://doi.org/10.1582/LEUKOS.2006.03.02.002

Galasiu, A. D., & Veitch, J. A. (2006). Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review. *Energy and Buildings*, *38*(7), 728–742. https://doi.org/10.1016/j.enbuild.2006.03.001

Geerdinck, L. M., & Schlangen, L. J. M. (2006). Well-Being Effects of High Color Temperature Lighting in Office and Industry. *2nd CIE Expert Symposium on Lighting and Health*, 126–130.

Gene-Harn, L., Keumala, N. I. M., & Ghafar, N. A. (2016). Office Occupants' Mood and Preference of Task Ambient Lighting in the Tropics. *MATEC Web of Conferences*, *66*. https://doi.org/10.1051/matecconf/20166600031

Gensler. (2008). *Workplace Survey United States - a Design and Performance report*. *Gensler*. Retrieved from http://www.gensler.com/uploads/document/129/file/2008_Gensler_Workplace_Survey_UK_09_30_2009.pdf

Gentile, N., Laike, T., & Dubois, M. C. (2016). Lighting control systems in individual offices rooms at high latitude: Measurements of electricity savings and occupants' satisfaction. *Solar Energy*, *127*, 113–123. https://doi.org/10.1016/j.solener.2015.12.053

Gifford, R. (1988). Light, decor, arousal, comfort and communication. *Journal of Environmental Psychology*, *8*(3), 177–189. https://doi.org/10.1016/S0272-4944(88)80008-2

Gillis, K., & Gatersleben, B. (2015). A Review of Psychological Literature on the Health and Wellbeing Benefits of Biophilic Design. *Buildings*, *5*(3), 948–963. https://doi.org/10.3390/buildings5030948

Gornicka, G. B. (2008). *Lighting at Work: Environmental study of direct effects of Lighting level and spectrum* *on psychophysiological variables*. Eindhoven University of Technology. https://doi.org/10.6100/IR639378

Gupta, R., Cudmore, T., & Bruce-onuah, A. (2016). Desktop investigation to examine the relationship between indoor environmental conditions and productivity in work spaces. In *Sustainable Ecological Engineering Design for Society (SEEDS)* (pp. 207–218).

Harter, J. K., Schmidt, F. L., Agrawal, S., Plowman, S. K., & Blue, A. (2016). *The Relationship Between Engagement at Work and Organizational Outcomes: 2016 Q12 Meta-Analysis: Ninth Edition*.

Heerwagen, J. H. (1998). Design, productivity and well-being: What are the Links? In *The American Institute of Architects Conference on Highly Effective Facilitie* (pp. 1–23). Retrieved from http://www.greenplantsforgreenbuildings.org/attachments/contentmanagers/25/DesignProductivityWellbeing.pdf

Heydarian, A., Carneiro, J. P., Gerber, D., & Becerik-Gerber, B. (2015). Immersive virtual environments, understanding the impact of design features and occupant choice upon lighting for building performance. *Building and Environment*, *89*, 217–228. https://doi.org/10.1016/j.buildenv.2015.02.038

Heydarian, A., Pantazis, E., Carneiro, J. P., Gerber, D., & Becerik-Gerber, B. (2016). Lights, building, action: Impact of default lighting settings on occupant behaviour. *Journal of Environmental Psychology*, *48*, 212–223. https://doi.org/10.1016/j.jenvp.2016.11.001

Heydarian, A., Pantazis, E., Wang, A., Gerber, D., & Becerik-Gerber, B. (2017). Towards user centered building design: Identifying end-user lighting preferences via immersive virtual environments. *Automation in Construction*, *81*, 56–66. https://doi.org/10.1016/j.autcon.2017.05.003

Hoffmann, G., Gufler, V., Griesmacher, A., Bartenbach, C., Canazei, M., Staggl, S., & Schobersberger, W. (2008). Effects of variable lighting intensities and colour temperatures on sulphatoxymelatonin and subjective mood in an experimental office workplace. *Applied Ergonomics*, *39*(6), 719–728. https://doi.org/10.1016/j.apergo.2007.11.005

Illuminating Engineering Society. (2011). *Lighting Handbook 10th Edition*.

International WELL Building Institute. (2016). *The WELL Building Standard*.

Iskra-Golec, I., Wazna, A., & Smith, L. (2012). Effects of blue-enriched light on the daily course of mood, sleepiness and light perception: A field experiment. *Lighting Research and Technology*, *44*(4), 506–513. https://doi.org/10.1177/1477153512447528

Islam, M. S., Dangol, R., Hyvarinen, M., Bhusal, P., Puolakka, M., & Halonen, L. (2015). User acceptance studies for LED office lighting: Lamp spectrum, spatial brightness and illuminance. *Lighting Research and Technology*, *47*, 54–79. https://doi.org/10.1177/1477153513514425

Kellert, S. R., & Calabrese, E. F. (2015). *The practice of biophilic design*. www.biophilic-design.com.

Kent, M. G., Cheung, T., Altomonte, S., Schiavon, S., & Lipczyńska, A. (2018). A Bayesian method of evaluating discomfort due to glare: The effect of order bias from a large glare source. *Building and Environment*, *146*(October), 258–267. https://doi.org/10.1016/j.buildenv.2018.10.005

Kent, M. G., Fotios, S., & Altomonte, S. (2018). An Experimental Study on the Effect of Visual Tasks on Discomfort Due to Peripheral Glare. *LEUKOS*, *June*(00), 1–12.

https://doi.org/10.1080/15502724.2018.1489282

Kim, S. Y., & Kim, J. J. (2007a). Influence of light fluctuation on occupant visual perception. *Building and Environment*, *42*(8), 2888–2899. https://doi.org/10.1016/j.buildenv.2006.10.033

Kim, S. Y., & Kim, J. J. (2007b). The effect of fluctuating illuminance on visual sensation in a small office. *Indoor and Built Environment*, *16*(4), 331–343. https://doi.org/10.1177/1420326X06079947

Kirsch, R., & Völker, S. (2014). Solid state lighting in offices: impact on lighting quality and room appearance. *CIE X039:2014*, *7*, 88–95.

Knoll. (2011). *Shaping the Dynamic Workplace: An overview of Recent Knoll Research*.

Kombeiz, O., Steidle, A., & Dietl, E. (2017). View it in a different light: Mediated and moderated effects of dim warm light on collaborative conflict resolution. *Journal of Environmental Psychology*, *51*, 270–283. https://doi.org/10.1016/j.jenvp.2017.04.007

Korte, E. M. De, Spiekman, M., Oeffelen, L. H., Zande, B. Van Der, Vissenberg, G., Huiskes, G., & Kuijt-evers, L. F. M. (2015). Personal environmental control : Effects of pre-set conditions for heating and lighting on personal settings , task performance and comfort experience. *Building and Environment*, *86*, 166–176. https://doi.org/10.1016/j.buildenv.2015.01.002

Krzyszczuk, K. M., & Boyce, P. R. (2002). Detection of slow light level reduction. *Journal of Illuminating Engineering Society*, *31*(2), 3–10.

Küller, R., Ballal, S., Laike, T., Mikellides, B., & Tonello, G. (2006). The impact of light and colour on psychological mood: a cross-cultural study of indoor work environments. *Ergonomics*, *49*(14), 1496–1507. https://doi.org/10.1080/00140130600858142

Lamb, S., & Kwok, K. C. S. (2016). A longitudinal investigation of work environment stressors on the performance and wellbeing of office workers. *Applied Ergonomics*, *52*, 104–111. https://doi.org/10.1016/j.apergo.2015.07.010

Lashina, T. A., Chraibi, S., Despenic, M., Shrubsole, P., & Rosemann, A. L. P. (2019). Sharing lighting control in an open office: Doing one's best to avoid conflict. *Building and Environment*, *148*(October 2018), 1–10. https://doi.org/10.1016/j.buildenv.2018.10.040

Lashina, T. A., Van der Vleuten-Chraibi, S., Despenic, M., Shrubsole, P., Rosemann, A. L. P., & van Loenen, E. J. (2019). A comparison of lighting control strategies for open offices. *Building and Environment*, *149*, 68–78. https://doi.org/10.1016/j.buildenv.2018.12.013

Leaman, A., & Bordass, B. (1993). Building Design, Complexity and Manageability. *Facilities*, *11*(9), 16–27. https://doi.org/10.1108/EUM0000000002256

Lee, S. Y., & Brand, J. L. (2005). Effects of Control Over Office Workspace on Perceptions of the Work Environment and Work Outcomes. *Journal of Environmental Psychology*, *25*, 323–333. https://doi.org/10.1016/j.jenvp.2005.08.001

Leesman. (2016). *Activity Based Working - The rise and rise of ABW: Reshaping the physical, virtual and behavioural workspace*. London.

Leesman. (2017). *The next 250K*. London. Retrieved from https://www.leesmanindex.com/250k_Report.pdf

Linhart, F., & Scartezzini, J. L. (2011). Evening office lighting - visual comfort vs. energy efficiency vs. performance? *Building and Environment*, *46*(5), 981–989. https://doi.org/10.1016/j.buildenv.2010.10.002

Lloyd, S. P. (1982). Least Squares Quantization in PCM. *IEEE Transactions on Information Theory*, *28*(2), 129–137. https://doi.org/10.1109/TIT.1982.1056489

Lockley, S. W., Evans, E. E., Scheer, F. A. J. L., Brainard, G. C., Czeisler, C. A., & Aeschbach, D. (2006). Short-Wavelength Sensitivity for the Direct Effects of Light on Alertness , Vigilance , and the Waking Electroencephalogram in Humans. *Sleep*, *29*(2), 161–168.

Loe, L., Mansfield, K. P., Rowlands, E., Loe, D. L., Mansfield, K. P., & Rowlands, E. (1994). Appearance of lit environment and its relevance in lighting design: Experimental study. *Lighting Research and Technology*, *26*(3), 119–133. https://doi.org/10.1177/096032719402600301

Logadottir, A., Christoffersen, J., & Fotios, S. A. (2011a). Investigating the use of an adjustment task to set the preferred illuminance in a workplace environment. *Lighting Research and Technology*, *43*(4), 403–422. https://doi.org/10.1177/1477153511400971

Logadottir, A., Christoffersen, J., & Fotios, S. A. (2011b). Investigating the use of an adjustment task to set the preferred illuminance in a workplace environment. *Lighting Research and Technology*, *43*(4), 403–422. https://doi.org/10.1177/1477153511400971

Manav, B. (2007). An experimental study on the appraisal of the visual environment at offices in relation to colour temperature and illuminance. *Building and Environment*, *42*(2), 979–983. https://doi.org/10.1016/j.buildenv.2005.10.022

Matthews, G., Jones, D. M., & Chamberlain, A. G. (1990). Refining the measurement of mood: The UWIST Mood Adjective Checklist. *British Journal of Psychology*, *81*, 17–42.

Matusiak, B. S., & Klöckner, C. A. (2016). How we evaluate the view out through the window. *Architectural Science Review*, *59*(3), 203–211.

Meerbeek, B. W., Gritti, T., Aarts, M. P. J., van Loenen, E. J., & Aarts, E. (2014). Building automation and perceived control : A field study on motorized exterior blinds in Dutch offices. *Building and Environment*, *79*, 66–77. https://doi.org/10.1016/j.buildenv.2014.04.023

Mills, P. R., 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. https://doi.org/10.1186/1740-3391-5-2

Moore, T., Carter, D. J., & Slater, A. I. (2000). Conflict and Control : The use of locally addressable lighting in open plan office space. In *Proceedings of the Chartered Institute of Buidling Service*.

Moore, T., Carter, D. J., & Slater, A. I. (2002a). A field study of occupant controlled lighting in offices. *Lighting Research and Technology*, *43*(3), 191–205.

Moore, T., Carter, D. J., & Slater, A. I. (2002b). User attitudes towards occupant controlled office lighting. *Lighting Research and Technology*, *34*(3), 207–219.

Moore, T., Carter, D. J., & Slater, A. I. (2003a). A qualitative study of occupant controlled of office lighting. *Lighting Research and Technology*, *35*(4), 297–317.

Moore, T., Carter, D. J., & Slater, A. I. (2003b). Long-term patterns of use of occupant controlled office lighting. *Lighting Research & Technology*, *35*(1), 43–59.

Moore, T., Carter, D. J., & Slater, A. I. (2004). A study of opinion in offices with and without user controlled lighting. *Lighting Research and Technology*, *36*(2), 131–146. https://doi.org/10.1191/13657828041i109oa

Münch, M., Linhart, F., Borisuit, A., Jaeggi, S. M., & Scartezzini, J. L. (2012). Effects of prior light exposure on early evening performance, subjective sleepiness, and hormonal secretion. *Behavioral Neuroscience*, *126*(1), 196–203. https://doi.org/10.1037/a0026702

NEN-EN 12464-1. (2011). *Light and lighting - Lighting of work places - Part 1: Indoor work places*.

Newsham, G. R., Aries, M. B. C., Mancini, S., & Faye, G. (2008). Individual control of electric lighting in a daylit space. *Lighting Research and Technology*, *40*(1), 25–41. https://doi.org/10.1177/1477153507081560

Newsham, G. R., & Mancini, S. (2006). The Potential for Demand-Responsive Lighting in The Potential for Demand-Responsive Lighting in Non-daylit Offices. *The Journal of the Illuminating Engineering Society of North America*, *3*(2), 105–120. https://doi.org/10.1582/LEUKOS.2006.03.02.002

Newsham, G. R., Mancini, S., & Marchand, R. G. (2008). Detection and Acceptance of Demand-Responsive Lighting in Offices with and without Daylight. *LEUKOS - Journal of Illuminating Engineering Society of North America*, *4*(3), 139–156. https://doi.org/10.1582/LEUKOS.2007.004.03.001

Newsham, G. R., Marchand, R. G., & Veitch, J. A. (2004). Preferred surface luminances in offices, by evolution. *Journal of the Illuminating Engineering Society*, *33*(1), 14–29.

Newsham, G. R., & Veitch, J. A. (2001). Lighting quality recommendations for VDT offices: a new method of derivation. *Lighting Research and Technology*, *33*(2), 97–113. https://doi.org/10.1177/136578280103300205

Newsham, G. R., Veitch, J. A., Arsenault, C. D., & Duval, C. L. (2004a). Effect of dimming control on office worker satisfaction and performance. In *IESNA Annual Conference Proceedings* (pp. 19–41). Tampa, Florida.

Newsham, G. R., Veitch, J. A., Arsenault, C. D., & Duval, C. L. (2004b). Effect of dimming control on office worker satisfaction and performance A version of this document is published in / Une version de ce document se trouve dans :, 19–41.

Newsham, G. R., Veitch, J. A., Arsenault, C. D., & Duval, C. L. (2004c). *Lighting for VDT Workstations 2 : Effect of Control and Lighting Design on Task Performance , and Chosen Photometric Conditions*.

Niemantsverdriet, K. (2018). *Designing Interactions with Shared Systems.* Eindhoven University of Technology, Eindhoven.

Niemantsverdriet, K., Broekhuijsen, M., Van Essen, H., & Eggen, B. (2016). Designing for Multi-User Interaction in the Home Environment. *Proceedings of the 2016 ACM Conference on Designing Interactive Systems - DIS '16*, (December 2017), 1303–1314. https://doi.org/10.1145/2901790.2901808

O'Brien, W., & Gunay, H. B. (2014). The contextual factors contributing to occupants ' adaptive comfort behaviors in offices e A review and proposed modeling framework. *Building and Environment*, *77*, 77–87. https://doi.org/10.1016/j.buildenv.2014.03.024

Osterhaus, W. K. E. (2005). Discomfort glare assessment and prevention for daylight applications in office environments. *Solar Energy*, *79*(2), 140–158. https://doi.org/10.1016/j.solener.2004.11.011

Pallant, J. (2002). *SPSS: Survival Manual. A step by step guide to data analysis using SPSS for Windows* (2nd ed.). Sidney: Allen & Unwin Australia.

Park, B. C., Chang, J. H., Kim, Y. S., Jeong, J. W., & Choi, A. S. (2010). A study on the subjective response for corrected colour temperature conditions in a specific space. *Indoor and Built Environment*, *19*(6), 623–637. https://doi.org/10.1177/1420326X10383472

Partonen, T., & Lönnqvist, J. (2000). *Bright light improves vitality and alleviates distress in healthy people*. *Journal of Affective Disorders* (Vol. 57). https://doi.org/10.1016/S0165-0327(99)00063-4

Phipps-nelson, J., Redman, J. R., Schlangen, L. J. M., & Shantha, M. W. (2009). Blue light Exposure Reduces Objective Measures of Sleepiness during Prolonged Nighttime Performance Testing. *Chronobiology International*, *26*(5), 891–912. https://doi.org/10.1080/07420520903044364

Rautkylä, E., Puolakka, M., Tetri, E., & Halonen, L. (2010). Effects of Correlated Colour Temperature and Timing of Light Exposure on Daytime Alertness in Lecture Environments. *Journal of Light & Visual Environment*, *34*(2), 59–68. https://doi.org/10.2150/jlve.34.59

Reinhart, C. F., & Voss, K. (2003). Monitoring manual control of electric lighting and blinds. *Lighting Research and Technology*, *35*(3), 243–260.

Rubinstein, F. M., & Enscoe, A. (2010). Saving energy with highly-controlled lighting in an open-plan office. *LEUKOS - Journal of Illuminating Engineering Society of North America*, *7*(1), 21–36. https://doi.org/10.1582/LEUKOS.2010.07.01002

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. https://doi.org/10.1152/ajpregu.00121.2005

Russel, J., & Mehrabian, A. (1977). Evidence for a three-factor theory of emotions. *Journal of Research in Personality*, *11*, 273–294.

Sadeghi, S. A., Karava, P., Konstantzos, I., & Tzempelikos, A. (2016). Occupant interactions with shading and lighting systems using different control interfaces: A pilot field study. *Building and Environment*, *97*, 177–195. https://doi.org/10.1016/j.buildenv.2015.12.008

Shamsul, B. M. T., Sia, C. C., Ng, Y. G., & Karmeg, K. (2013). Effects of Light's Colour Temperatures on Visual Comfort Level, Task Performances, and Alertness among Students. *American Journal of Public Health Research*, *1*(7), 159–165. https://doi.org/10.12691/ajphr-1-7-3

Sheedy, J. E., Smith, R. O. B., & Hayes, J. (2005). Visual effects of the luminance surrounding a computer display, *48*(9), 1114–1128. https://doi.org/10.1080/00140130500208414

Shikakura, T., Morikawa, H., & Nakamura, Y. (2003). Perception of lighting fluctuation in office lighting environment. *Journal Light Visual Environment*, *27*, 75–82.

Shishegar, N., & Boubekri, M. (2016). Natural Light and Productivity: Analyzing the Impacts of Daylighting on Students' and Workers' Health and Alertness. *Ijacebs*, *3*(1), 72–77. https://doi.org/10.15242/IJACEBS.AE0416104

Simpson, J. A., & Weinier, E. S. . (1989). The Oxford English Dictionary. Retrieved June 6, 2018, from http://www.oxforddictionaries.com/definition/english/wellbeing

Smiggels, V. M. H. H. (2017). *Lighting Experience at the Edge - graduation thesis*. Erasmus University NL.

Smolders, K. C. H. J., & de Kort, Y. A. W. (2017). Investigating daytime effects of correlated colour temperature on experiences, performance, and arousal. *Journal of Environmental Psychology*, *50*, 80–93. https://doi.org/10.1016/j.jenvp.2017.02.001

Smolders, K. C. H. J., de Kort, Y. A. W., & Cluitmans, P. J. M. (2012). A higher illuminance induces alertness even during office hours: findings on subjective measures, task performance and heart rate measures. *Physiology & Behavior*, *107*(1), 7–16. https://doi.org/10.1016/j.physbeh.2012.04.028

Steelcase. (2016). *Steelcase Global Report: Engagement and the Global Workplace*. Retrieved from https://www.steelcase.com/steelcase-global-report/

Steidle, A., & Werth, L. (2013). Freedom from constraints: Darkness and dim illumination promote creativity. *Journal of Environmental Psychology*, *35*, 67–80. https://doi.org/10.1016/j.jenvp.2013.05.003

Sullivan, J. T., & Donn, M. (2016). Light distribution and spatial brightness: relative importance of the walls, ceiling and floor. In *CIE 2016 Lighting Quality and Energy Efficiency Conference, 2016. Melbourne, Australia*.

te Kulve, M., Schlangen, L. J. M., Schellen, L., Frijns, A. J. H., & van Marken Lichtenbelt, W. D. (2017). The impact of morning light intensity and environmental temperature on body temperatures and alertness. *Physiology and Behavior*, *175*, 72–81. https://doi.org/10.1016/j.physbeh.2017.03.043

Thayer, R. E. (1989). The biopsychology of mood and arousal. *New York: Oxford University Press*.

Tiller, D. K., & Veitch, J. A. (1995). Perceived room brightness : Pilot study on the effect of luminance distribution NRC Publications Archive (NPArC), (August 2016). https://doi.org/10.1177/14771535950270020401

Tuaycharoen, N., & Tregenza, P. R. (2005). Discomfort glare from interesting images. *Lighting Research & Technology*, *37*(4), 329–338. https://doi.org/10.1191/1365782805li147oa

Tuaycharoen, N., & Tregenza, P. R. (2007). View and discomfort glare from windows. *Lighting Research and Technology*, *39*(2), 185–198. https://doi.org/10.1177/1365782807077193

Uttley, J., Fotios, S. A., & Cheal, C. (2013). Satisfaction and illuminances set with user-controlled lighting, (March 2015), 37–41. https://doi.org/10.1080/00038628.2012.724380

van Bommel, W. J. M. (2006). Dynamic Lighting At Work – Both in Level and Colour. In *2nd CIE Expert Symposium on Light and Health, CIE* (pp. 62–67).

van Bommel, W. J. M., & van den Beld, G. J. (2004). Lighting for work: a review of visual and biological effects. *Lighting Research & Technology*, *36*(4), 255–266. https://doi.org/10.1191/1365782804li122oa

Van de Werff, T., Niemantsverdriet, K., Van Essen, H., & Eggen, B. (2017). Evaluating Interface Characteristics for Shared Lighting Systems in the Office Environment. *Proceedings of the 2017 Conference on Designing Interactive Systems - DIS '17*, 209–220. https://doi.org/10.1145/3064663.3064749 van Ooyen, M. H. F., van de Weijgert, J. A. C., & Begemann, S. H. A. (1987). Preferred Luminances in Offices. *Journal of the Illuminating Engineering Society*, *2*(16), 152–156. https://doi.org/10.1080/00994480.1987.10748695

Veitch, J. A. (2001). Psychological Processes Influencing Lighting Quality. *Journal of the Illuminating Engineering Society*, *30*(1), 124–140. https://doi.org/10.1080/00994480.2001.10748341

Veitch, J. A., Charles, K. E., Farley, K. M. J., & Newsham, G. R. (2007). A model of satisfaction with open-plan office conditions: COPE field findings. *Journal of Environmental Psychology*, *27*(3), 177–189. https://doi.org/10.1016/j.jenvp.2007.04.002

Veitch, J. A., Charles, K. E., Newsham, G. R., Marquardt, C. J. G., & Geerts, J. (2003). *Environmental Satisfaction in Open-Plan Environments: 5. Workstation and Physical Condition Effects*. *NRC-CNRC*.

Veitch, J. A., Donnelly, C. L., Galasiu, A. D., Newsham, G. R., Sander, D. M., & Arsenault, C. D. (2010). *Office Occupants' Evaluations of an Individually-controllable Lighting System*. *National Research Council Canada*. Ottowa.

Veitch, J. A., Farley, K. M. J., & Newsham, G. R. (2002). *Environmental Satisfaction in Open-plan Environments: 1 Scale Validation and Methods*.

Veitch, J. A., Geerts, J., Charles, K. E., Newsham, G. R., & Marquardt, C. J. G. (2005). Satisfaction with lighting in open-plan offices: COPE field findings. In *Proceedings of Lux Europa - 10th European Lighting Conference 2005* (pp. 414–417).

Veitch, J. A., & Newsham, G. R. (2000a). Exercised Control, Lighting Choices, and Energy Use: an Office Simulation Experiment. *Journal of Environmental Psychology*, *20*(3), 219–237. https://doi.org/10.1006/jevp.1999.0169

Veitch, J. A., & Newsham, G. R. (2000b). Preferred luminous conditions in open-plan offices: research and practice recommendations. *Lighting Research and Technology*, *32*(4), 199–212. https://doi.org/10.1177/096032710003200404

Veitch, J. A., Newsham, G. R., Boyce, P. R., & Jones, C. C. (2008). Lighting appraisal, well-being and performance in open-plan offices: A linked mechanisms approach. *Lighting Research and Technology*, *40*(2), 133–148. https://doi.org/10.1177/1477153507086279

Veitch, J. A., Stokkermans, M. G. M., & Newsham, G. R. (2011). Linking Lighting Appraisals to Work Behaviors. *Environment and Behavior*, *45*(2), 198–214. https://doi.org/10.1177/0013916511420560

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 & Health*, *34*(4), 297–306. https://doi.org/10.5271/sjweh.1268

Vischer, J. C. (2007). The effects of the physical environment on job performance: Towards a theoretical model of workspace stress. *Stress and Health*, *23*(3), 175–184. https://doi.org/10.1002/smi.1134

Wang, M. L., & Luo, M. R. (2017). Effects of LED lighting on office work performance. In *Conference Proceedings - 2016 13th China International Forum on Solid State Lighting, SSLCHINA 2016* (pp. 119–122). State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou, China: IEEE. https://doi.org/10.1109/SSLCHINA.2016.7804366

Wei, M., Houser, K. W., Orland, B., Lang, D. H., Ram, N., Sliwinski, M. J., & Bose, M. (2014). Field study of office worker responses to fluorescent lighting of different CCT and lumen output. *Journal of Environmental Psychology*, *39*, 62–76. https://doi.org/10.1016/j.jenvp.2014.04.009

Williams, A., Atkinson, B., Garbesi, K., Page, E., & Rubinstein, F. M. (2012). Lighting Controls in Commercial Buildings. *LEUKOS - Journal of Illuminating Engineering Society of North America*, *8*(3), 161–180. https://doi.org/10.1582/LEUKOS.2012.08.03.001

Wright, M., Hill, S., Cook, G., & Bright, K. (1999). The perception of lighting quality in a non-uniformly lit office environment. *Facilities*, *17*(12/13), 476–484.

Yang, S., Shuguang, K., Weixi, Z., Sheng, P., Mi, T., Kangjun, L., & Xingtao, Z. (2014). Study of preferred background luminance in watching computer, *127*(11), 2073–2077. https://doi.org/10.3760/cma.j.issn.0366-6999.20133232

Appendix

Appendix

Appendix A: Lighting preference profiles

Chapter 3 presents the preference profiles that are derived based on users' activeness, dominance, tolerance, and lighting level preference. This Appendix presents a description of the methodology used to derive the tolerance and dimming level preference of users, as also published in (Despenic et al., 2017).

For tolerance and dimming level preference the number of classes are unknown. Therefore, classification of users regarding these features is done by unsupervised learning. The task of unsupervised learning is to infer classes by properly describing a hidden structure of unlabelled data. For this task, the K-means clustering algorithm is used (Lloyd, 1982).

Suppose a given data $\{x_1, \ldots, x_2\}$ set consists of N observations that are D-dimensional. The K-means algorithm will partition the data into K number of clusters such that their inter-point distances within a cluster are small compared to distances to points outside the cluster. The μ_k, where $k= 1; \ldots; K$, are D-dimensional vectors, representing the centres of the clusters. The goal is to find an assignment of each data point to clusters, as well as a set of vectors $\{ \mu_k \}$, such that the sum of squares of the distances of each data point to its closest vector μ_k is minimal. The formal mathematical representation of the K-means algorithm is given in (Bishop, 2006).

To validate and interpret the consistency within each cluster of data, the silhouette criterion, introduced by Rousseeuw (1987) is used. A silhouette is a measure representing how similar a data point is to its own cluster compared to other clusters. The main advantage of the silhouette criterion is that it does not assume that class labels are available, since, in this analysis, labels of users regarding tolerance and preference are unknown a priori. A silhouette value of the i^{th} point S_i is given as:

$$S_i = \frac{b_i - a_i}{\max(a_i, b_i)}$$

where a_i is the average distance from the i^{th} point to the other points in the same cluster as i, while b_i is the minimum average distance from the i^{th} point to points in a different cluster, minimized over clusters. The silhouette value ranges from -1 to 1, where high values indicate that a data point is matched well with its own cluster and poorly to neighbouring clusters. When S_i is large, having a value close to 1, it implies that within cluster dissimilarity a_i is much smaller than the smallest between cluster dissimilarity b_i. Therefore, the i^{th} point is well-clustered and it is assigned to the appropriate cluster. A different case is when S_i is close to zero. In that case, a_i and b_i are approximately equal and it is not clear whether the i^{th} point should be assigned to either of the two clusters, since the i^{th} point lies equally far from both. When the value of S_i is close to -1, a_i is much larger than b_i meaning that i^{th} point is much closer to the other cluster than to the one it has been assigned to and this point is considered 'misclassified'. If the majority of the data points have high silhouette values (above 0.5), the clustering is appropriate. If the majority of the data points show low (below 0.5) or negative silhouette values, the clustering configuration either has too few or too many clusters. Values around zero indicate overlapping clusters. The average value of S_i over all data points in the entire data set is a measure of how appropriately the data has been clustered.

References: Lloyd, S. P., Least squares quantization in PCM, IEEE Trans. Inf. Theory 28 (2) (1982) p129-137. Bishop, C., Pattern Recognition and Machine Learning, Springer-Verlag NY, Inc, Secaucus, NJ, USA, 2006. Rousseeuw, P., Silhouettes: a graphical aid to the interpretation and validation of cluster analysis, J. Comput. Appl. Math. 20 (1987) p53-65.

Appendix B: Influence of wall brightness

This Appendix presents an extensive overview of the design and results of the study reported in Chapter 4.

Table B.1 Average horizontal illuminance at desk 4 for the different dimming levels of the 'control group' luminaires.

Dimming level in percentage	Desk illuminance in lx at desk 4					
	N50	U50	N100	U100	N200	U200
1	311	308	321	311	293	335
10	349	346	359	349	331	373
20	391	388	401	391	373	415
30	433	430	443	433	415	457
40	475	472	485	475	457	499
50	517	514	527	517	499	541
60	559	556	569	559	541	583
70	601	598	611	601	583	625
80	643	640	653	643	625	667
90	685	682	695	685	667	709
100	727	724	737	727	709	751

Table B.2. Overview of the sequences in which the light conditions were evaluated.

	Sequence					
	1	2	3	4	5	6
Trial 1	N50	N100	N200	N50	N100	N200
	U50	U100	U200	U100	U50	U50
	N100	N200	N50	N200	U100	N100
	U100	U200	U50	U50	N200	U200
	N200	N50	N100	N100	U200	N50
	U200	U50	U100	U200	N50	U100
Trial 2	N100	N200	N50	N100	U200	U200
	N200	U50	N100	U50	U100	U100
	U50	U100	U50	U100	U50	U50
	U100	U200	U100	N200	N50	N100
	U200	N50	U200	U200	N200	N50
	N50	N100	N200	N50	N100	N200

Paired samples t-test are performed, with effect size calculations done using eta squared ($\eta^2 = t^2/(t^2 + N - 1$); with 0.01=small effect, 0.06=moderate effect, and 0.14=large effect (Cohen (1988) from Field, 2009; Pallant, 2002).

Table B.3. Results paired samples test on wall uniformity.

	Sig. (2-tailed)	Effect size	Mean difference in lx
N50$_{min}$ - U50$_{min}$	0.411	0.01	-4
N50$_{def}$ - U50$_{def}$	0.054	0.07	-18
N50$_{max}$ - U50$_{max}$	0.540	0.01	-6

	Sig. (2-tailed)	Effect size	Mean difference in lx
N200$_{min}$ - U200$_{min}$	0.000	0.59	-47
N200$_{def}$ - U200$_{def}$	0.011	0.12	-22
N200$_{max}$ - U200$_{max}$	0.000	0.44	-43

N100$_{min}$ - U100$_{min}$	0.956	0.00	0
N100$_{def}$ - U100$_{def}$	0.222	0.03	10
N100$_{max}$ - U100$_{max}$	0.734	0.00	-3

Table B.4. Results paired samples test on average wall luminance.

	Sig. (2-tailed)	Effect size	Mean difference in lx
X50$_{min}$ - U200$_{min}$	0.000	0.42	-37
X50$_{def}$ - U200$_{def}$	0.299	0.02	9
X50$_{max}$ - U200$_{max}$	0.000	0.23	-33

	Sig. (2-tailed)	Effect size	Mean difference in lx
X50$_{min}$ - N200$_{min}$	0.025	0.09	10
X50$_{def}$ - N200$_{def}$	0.002	0.18	31
X50$_{max}$ - N200$_{max}$	0.219	0.03	10

X100$_{min}$ - U200$_{min}$	0.000	0.25	-29
X100$_{def}$ - U200$_{def}$	0.677	0.00	-4
X100$_{max}$ - U200$_{max}$	0.000	0.24	-31

X100$_{min}$ - N200$_{min}$	0.001	0.18	18
X100$_{def}$ - N200$_{def}$	0.057	0.07	18
X100$_{max}$ - N200$_{max}$	0.072	0.06	13

X50$_{min}$ - X100$_{min}$	0,082	0.06	-8
X50$_{def}$ - X100$_{def}$	0,106	0.05	13
X50$_{max}$ - X100$_{max}$	0,673	0.00	-3

Table B.5. Results paired samples test per distraction group – effect of wall uniformity on the preferred desk illuminance.

	Average distracted group (n=47)		Fast distracted group (n=7)			Average distracted group (n=47)		Fast distracted group (n=7)	
	Sig. (2-tailed)	Effect size	Sig. (2-tailed)	Effect size		Sig. (2-tailed)	Effect size	Sig. (2-tailed)	Effect size
$N50_{min}$ - $U50_{min}$	0.502	0.01	0.510	0.09	$N200_{min}$ - $U200_{min}$	0.000	0.57	0.006	0.77
$N50_{def}$ - $U50_{def}$	0.112	0.06	0.197	0.30	$N200_{def}$ - $U200_{def}$	0.024	0.11	0.223	0.27
$N50_{max}$ - $U50_{max}$	0.696	0.00	0.550	0.07	$N200_{max}$ - $U200_{max}$	0.000	0.47	0.165	0.33
$N100_{min}$ - $U100_{min}$	0.945	0.00	0.882	0.00					
$N100_{def}$ - $U100_{def}$	0.366	0.02	0.357	0.17					
$N100_{max}$ - $U100_{max}$	0.808	0.00	0.252	0.24					

Table B.6. Results paired samples test per distraction group – effect of average wall luminance on the preferred desk illuminance.

	Average distracted group (n=47)		Fast distracted group (n=7)			Average distracted group (n=47)		Fast distracted group (n=7)	
	Sig. (2-tailed)	Effect size	Sig. (2-tailed)	Effect size		Sig. (2-tailed)	Effect size	Sig. (2-tailed)	Effect size
$X50_{min}$ - $U200_{min}$	0.000	0.40	0.007	0.76	$X50_{min}$ - $N200_{min}$	0.038	0.09	0.331	0.18
$X50_{def}$ - $U200_{def}$	0.340	0.02	0.714	0.03	$X50_{def}$ - $N200_{def}$	0.005	0.16	0.128	0.38
$X50_{max}$ - $U200_{max}$	0.000	0.26	0.648	0.04	$X50_{max}$ - $N200_{max}$	0.450	0.01	0.096	0.44
$X100_{min}$ - $U200_{min}$	0.000	0.32	0.731	0.03	$X100_{min}$ - $N200_{min}$	0.005	0.16	0.143	0.36
$X100_{def}$ - $U200_{def}$	0.599	0.01	0.975	0.00	$X100_{def}$ - $N200_{def}$	0.069	0.07	0.543	0.08
$X100_{max}$ - $U200_{max}$	0.000	0.34	0.727	0.03	$X100_{max}$ - $N200_{max}$	0.271	0.03	0.127	0.38
$X50_{min}$ - $X100_{min}$	0.230	0.03	0.235	0.26					
$X50_{def}$ - $X100_{def}$	0.081	0.07	0.820	0.01					
$X50_{max}$ - $X100_{max}$	0.928	0.00	0.442	0.12					

Appendix C: Noticeability and acceptance of granular dimming

This Appendix presents an extensive overview of the results of the study reported in Chapter 5.

Table C.1 Results of the statistical tests regarding the effect of the first or second time a condition is evaluated in experiment 1.

	Acceptance					Noticeability				
Condition	1-1 ^{2}	2-2 ^{2}	3-3 ^{2}	4-4 ^{2}	6-6 ^{2}	1-1 ^{2}	2-2 ^{2}	3-3 ^{2}	4-4 ^{2}	6-6 ^{2}
Z [a]	-1.370[b]	-0.497[b]	-1.450[b]	-0.272[c]	-1.342[b]	-1.633[c]	-0.447[c]	-1.732[c]	-1.000[c]	-1.414[c]
Asymp. Sig. (2-tailed) [a]	0.171	0.619	0.147	0.785	0.180	0.102	0.655	0.083	0.317	0.157
Effect size [d]	-0.21	-0.08	-0.23	-0.04	-0.21	-0.26	-0.07	-0.27	-0.16	-0.22

a. Wilcoxon signed-rank tests, b. based on negative ranks, c. based on positive ranks, d. Pearson r, calculated using r=Z/√N *of Rosenthal (1994) (from: Field, 2009)*

Table C.2. Results of the statistical tests regarding the impact of dimming speed on noticeability and acceptance ratings in experiment 1.

		Noticeability		Acceptance	
0 vs 2 vs 5 s	Conditions	Chi-Square [a]	Asymp. Sig.[a]	Chi-Square [a]	Asymp. Sig.[a]
Person enters, dim up	1 – 2 – 3	34.667	0.000	33.612	0.000
No occ. change, dim up	4 – 5 – 6	34.414	0.000	32.822	0.000
0 vs 5 vs 10 s					
Person leaves, 5-min delay, dim down	7 – 9 – 10	39.714	0.000	33.495	0.000
Person leaves, no delay, dim down	11 – 12 – 13	46.519	0.000	43.931	0.000
No occ. change, dim down	14 – 16 – 17	45.852	0.000	41.826	0.000

a. Friedman Test, N=41 (p<0.05), df=2

Table C.3. Results of the statistical tests regarding the impact of dimming direction on acceptance ratings in experiment 1.

Dim up vs dim down	Labels	Z [a]	Asymp. Sig. (2-tailed) [a]	Effect size [c]
No occ. change, dim in 0 s, up vs down	4 – 14	-0.761 [b]	0.447	-0.12
No occ. change, dim in 5 s, up vs down	6 – 16	-0.537 [b]	0.591	-0.08

a. Wilcoxon Signed Ranks Test, b. Based on negative ranks, c. Pearson r, calculated using r=Z/√N *of Rosenthal (1994) (from: Field, 2009)*

Table C.4. Results of the statistical tests regarding the impact of occupancy change on acceptance ratings in experiment 1.

With vs without occupancy change	Labels	Z [a]	Asymp. Sig. (2-tailed) [a]	Effect size [d]
Dim up in 0 s	1 – 4	-0.193 [b]	0.847	-0.03
Dim up in 2 s	2 – 5	-0.286 [c]	0.775	-0.04
Dim up in 5 s	3 – 6	-0.314 [c]	0.754	-0.05
Dim down in 0 s (occ. change includes delay)	7 – 14	-0.490 [b]	0.624	-0.08
Dim down in 5 s (occ. change includes delay)	9 – 16	-1.138 [b]	0.255	-0.18
Dim down in 10 s (occ. change includes delay)	10 – 17	-1.089 [b]	0.276	-0.17
Dim down in 0 s (occ. change without delay)	11 – 14	-0.737 [c]	0.461	-0.12
Dim down in 5 s (occ. change without delay)	12 – 16	-1.211 [c]	0.226	-0.19
Dim down in 10 s (occ. change without delay)	13 – 17	-1.342 [c]	0.180	-0.21

a. Wilcoxon Signed Ranks Test, b. Based on positive ranks, c. Based on negative ranks, d. Pearson r, calculated using $r=Z/\sqrt{N}$ *of Rosenthal (1994) (from: Field, 2009)*

Table C.5. Results of the statistical tests regarding the impact of the delay after an occupancy change on the noticeability and acceptance ratings of dimming down in experiment 1.

		Noticeability			Acceptance		
With vs without delay after occupancy change	Labels	Z [a]	Asymp. Sig. (2-tailed) [a]	Effect size [d]	Z [a]	Asymp. Sig. (2-tailed) [a]	Effect size [d]
Dim down in 0 s	7 – 11	-0.707 [c]	0.480	-0.11	-1.432 [b]	0.153	-0.22
Dim down in 5 s	9 – 12	-2.121 [c]	0.034	-0.33	-2.083 [b]	0.037	-0.33
Dim down in 10 s	10 – 13	-1.000 [c]	0.317	-0.16	-1.511 [b]	0.131	-0.24

a. Wilcoxon Signed Ranks Test, b. Based on positive ranks, c. Based on negative ranks, d. Pearson r, calculated using $r=Z/\sqrt{N}$ *of Rosenthal (1994) (from: Field, 2009)*

Table C.6. Results of the statistical tests regarding the impact of informing participants of the potential occurrence of light changes on the noticeability and acceptance ratings of dimming down in experiment 1.

		Noticeability			Acceptance		
Informed vs not informed of light changes	Labels	Z[a]	Asymp. Sig. (2-tailed)[a]	Effect size[d]	Z[a]	Asymp. Sig. (2-tailed)[a]	Effect size[d]
Dim up in 0 s	4 – 4.I	-1.000[c]	0.317	-0.16	-0.827[b]	0.408	-0.13
Dim up in 2 s	5 – 5.I	-1.941[c]	0.052	-0.30	-1.394[b]	0.163	-0.22
Dim up in 5 s	6 – 6.I	-2.887[c]	0.004	-0.45	-2.940[b]	0.003	-0.46
Dim down in 0 s	14 – 14.I	-1.508[c]	0.132	-0.24	-0.424[b]	0.672	-0.07
Dim down in 5 s	16 – 16.I	-1.508[c]	0.132	-0.24	-1.410[b]	0.159	-0.22
Dim down in 10 s	17 – 17.I	-0.577[c]	0.564	-0.09	0.365[b]	0.715	0.06

a. Wilcoxon Signed Ranks Test, b. Based on negative ranks, c. Based on positive ranks, d. Pearson r, calculated using $r=Z/\sqrt{N}$ *of Rosenthal (1994) (from: Field, 2009)*

Table C.7. Results of the statistical tests regarding the impact of dimming speed on noticeability and acceptance ratings in experiment 2.

		Noticeability		Acceptance	
0 vs 2 vs 5 s	Labels	Chi-Square[a]	Asymp. Sig.[a]	Chi-Square[a]	Asymp. Sig.[a]
Person enters, dim up	1 – 2 – 3	10.667	0.005	6.343	0.042
No occ. change, dim up	4 – 5 – 6	20.462	0.000	24.041	0.000
Person leaves, 5-min delay, dim down	7 – 8 – 9	18.500	0.000	23.581	0.000
No occ. change, dim down	14 – 15 – 16	14.364	0.001	14.684	0.001

a. Friedman Test, N=17 ($p<0.05$), df=2

Table C.8. Results of the statistical tests regarding the impact of dimming direction on noticeability and acceptance ratings in experiment 2.

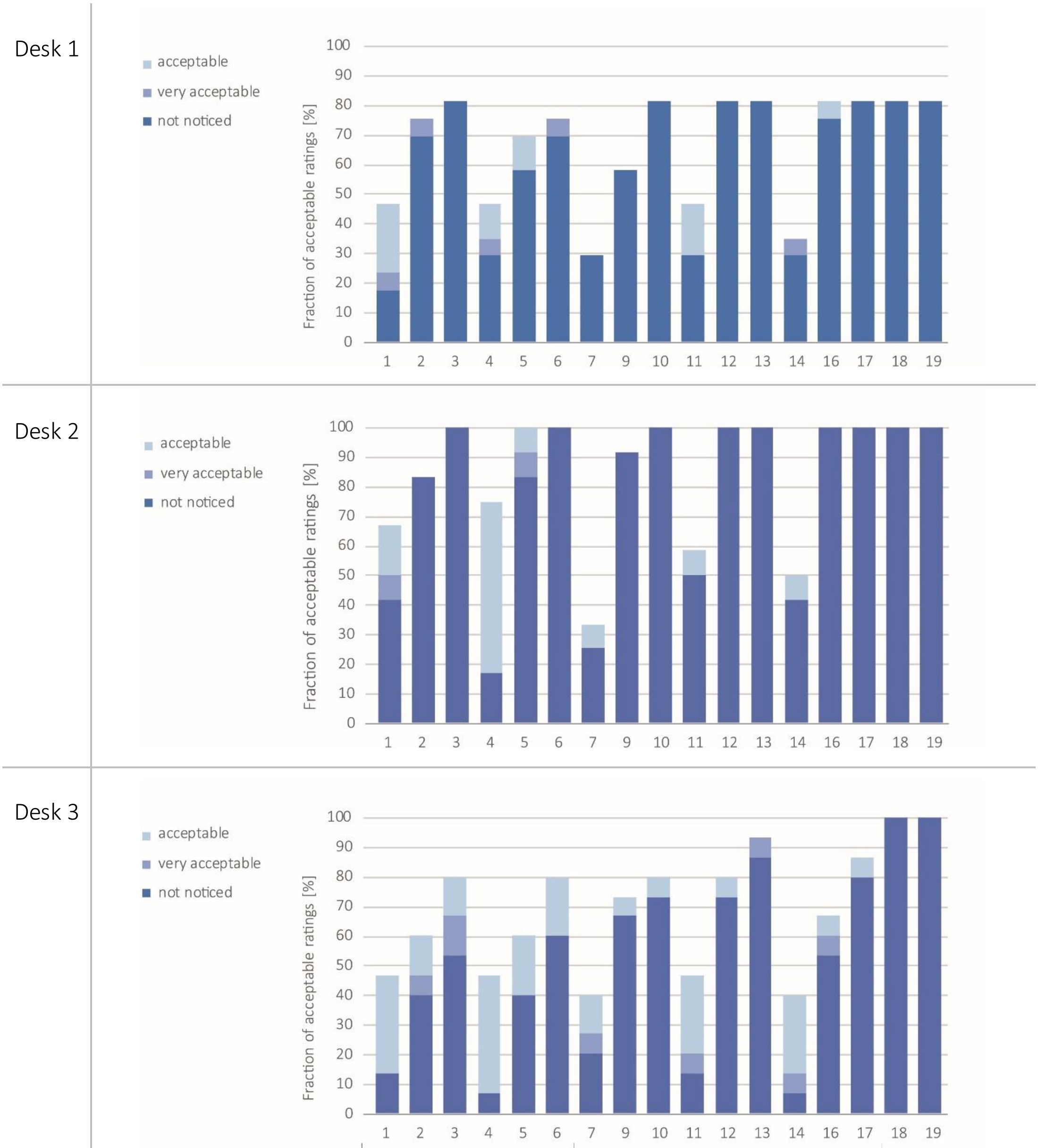
		Noticeability			Acceptance		
Dim up vs dim down	Labels	Z[a]	Asymp. Sig. (2-tailed)[a]	Effect size[d]	Z[a]	Asymp. Sig. (2-tailed)[a]	Effect size[d]
No occ. change, dim in 0 s, up vs down	4 – 14	-2.236[c]	0.025	-0.54	-1.902[b]	0.057	-0.46
No occ. change, dim in 2 s, up vs down	5 – 15	-1.342[c]	0.180	-0.33	-0.933[b]	0.351	-0.23
No occ. change, dim in 5 s, up vs down	6 – 16	-1.414[c]	0.157	-0.34	-1.342[b]	0.180	-0.33

a. Wilcoxon Signed Ranks Test, b. Based on negative ranks, c. Based on positive ranks, d. Pearson r, calculated using $r=Z/\sqrt{N}$ *of Rosenthal (1994) (from: Field, 2009)*

Table C.9. Results of the statistical tests regarding the impact of occupancy change on acceptance ratings in experiment 2.

With vs without occupancy change	Labels	Z [a]	Asymp. Sig. (2-tailed) [a]	Effect size [d]
Dim up in 0 s	1 – 4	-2.742 [b]	0.006	-0.67
Dim up in 2 s	2 – 5	-0.410 [c]	0.682	-0.10
Dim up in 5 s	3 – 6	-0.447 [c]	0.655	-0.11
Dim down in 0 s	7 – 14	-0.634 [c]	0.526	-0.15
Dim down in 2 s	8 – 15	-1.084 [b]	0.279	-0.26
Dim down in 5 s	9 – 16	-1.604 [c]	0.109	-0.39

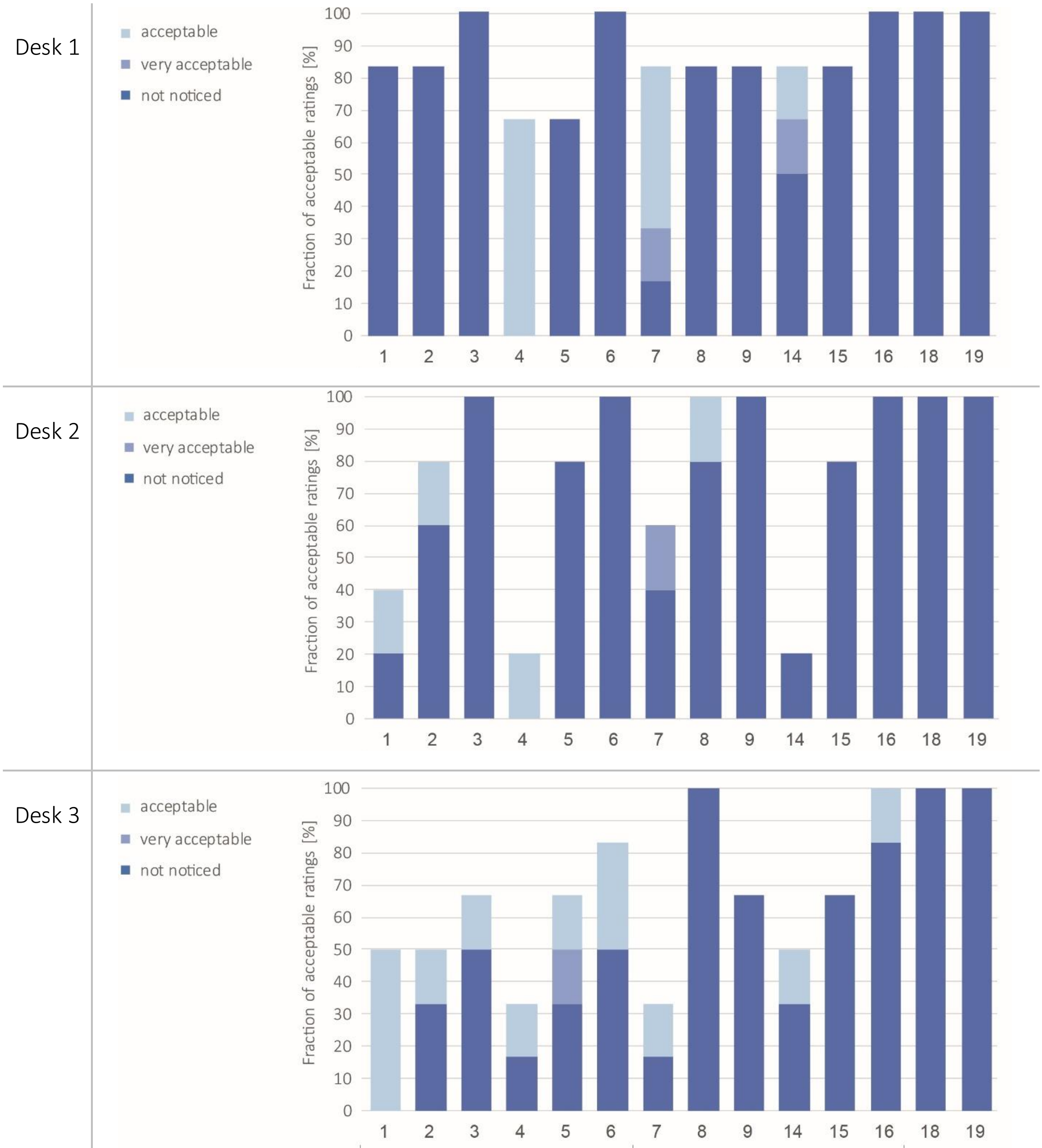
a. Wilcoxon Signed Ranks Test, b. Based on positive ranks, c. Based on negative ranks, d. Pearson r, calculated using r=Z/√N *of Rosenthal (1994) (from: Field, 2009)*



Lights	Dim up						Dim down									No change	
Actor	Enter			No change			Leave *			Leave			No change			Enter	Leave
Fading time [s]	0	2	5	0	2	5	0	5	10	0	5	10	0	5	10	-	

Conditions

*Figure C.1. Experiment 1 – desks 1,2, and 3: Fraction of participants that rated lighting conditions as acceptable, very acceptable, or not noticed. Conditions are sorted on ascending label numbers. Characteristics of each condition are shown below the bar chart. * Lights are dimmed down 5 min after the actor has left the office.*



Lights	Dim up						Dim down						-	
Actor	Enter			-			Leave *			-			Enter	Leave
Speed [s]	0	2	5	0	2	5	0	2	5	0	2	5		

Conditions

*Figure C.2. Experiment 2 - desks 1, 2, and 3: Fraction of participants that rated lighting conditions as acceptable, very acceptable, or not noticed. Conditions are sorted on ascending label numbers. Characteristics of each condition are shown below the bar chart. * Lights are dimmed down 5 min after the actor has left the office.*

Curriculum Vitae

Sanae van der Vleuten-Chraibi was born on 11-08-1985 in Haaksbergen, the Netherlands. After finishing her VWO at the Assink Lyceum in Haaksbergen in 2003, she started her studies at the Eindhoven University of Technology. After receiving her bachelor's degree in Architecture Building and Planning, she proceeded with the master specialization program Physics of the Built Environment. In 2011, she graduated on the topic of visual comfort in office environments, a project in which she collaborated with the startup Peer+, a company developing switchable glazing. After receiving her master's degree in 2011, she started her professional career with an assignment for TNO. In this assignment she designed and executed a user evaluation study, exploring user comfort with adaptive energy efficient facades. End of 2011, she joined the Research department User Experience and Interaction of Royal Philips B.V. In 2012 Sanae has worked as a visiting researcher at Philips North America, conducting user experience research for multiple lighting projects.

Since 2014, Sanae is employed by Signify, formerly named Philips Lighting, focusing her research work on the user experience of lighting. Sanae has been involved in several projects, coordinating and conducting research activities in which user needs and experiences are explored. In her last projects the role of lighting in user wellbeing and satisfaction in offices has been a central topic.

Besides her activities for the Office segment, Sanae has lead scenario planning activities for different domains, like Future of Retail and Future of Living. The created scenarios are used to stress test research programs and business strategies, and as input for future proof propositions. Sanae was co-responsible for the dissemination of the scenario planning method within the organization.

In 2014 she started a PhD project in the Building Lighting group of Alexander Rosemann at the Unit Building Physics and Services in the Department of the Built Environment at the Eindhoven University of Technology (TU/e). The results of this PhD project are presented in this dissertation.

List of publications

Journal Papers

Lashina TA, Van der Vleuten-Chraibi S, Despenic M, Shrubsole P, Rosemann ALP, Van Loenen EJ (2019). A comparison of lighting control strategies for open offices. Building and Environment 2019; 149: 68-78. Available from: https://doi.org/10.1016/j.buildenv.2018.12.013.

Lashina TA, Van der Vleuten-Chraibi S, Despenic M, Shrubsole P, Rosemann ALP, Van Loenen EJ (2019). Sharing lighting control in an open office: doing one's best to avoid conflict. Building and Environment 2019; 148: 1-10. Available from: https://doi.org/10.1016/j.buildenv.2018.10.040.

Chraibi S, Creemers PTJ, Rosenkotter C, Van Loenen EJ, Rosemann ALP, McCulloch-Aries MBC (2018). Dimming strategies for open office lighting: User experience and acceptance. Research and Technology 2018; 0: 1-17. Available from: https://doi.org/10.1177/1477153518772154

Chraibi S, Crommentuijn L, van Loenen EJ, Rosemann ALP (2017). Influence of wall luminance and uniformity on preferred task illuminance. Building and Environment 2017; 117: 24-35. Available from: http://dx.doi.org/10.1016/j.buildenv.2017.02.026

Despenic M, Chraibi S, Lashina TA, Rosemann ALP (2017). Lighting preference profiles of users in an open office environment. Building and Environment 2017; 116: 89-107. Available from: https://doi.org/10.1016/j.buildenv.2017.01.033

Chraibi S, Lashina TA, Shrubsole P, Aries MBC, van Loenen EJ, Rosemann ALP (2016). Satisfying light conditions: A field study on perception of consensus light in Dutch open office environments. Building and Environment. 2016; 105: 116-127. Available from: http://dx.doi.org/10.1016/j.buildenv.2016.05.032

Aarts MPJ, Chraibi S, Tenner AD (2011). Lichtontwerp voor een verpleeghuis voor mensen met dementie. Bouwfysica 2011; 22(2): 2-6.

Conference Papers

Creemers PTJ, van Loenen EJ, Aarts MPJ, Chraibi S, Lashina TA. Acceptable fading time of a granular controlled lighting system for co-workers in an open office. Proceedings Experiencing Light 2014 International Conference. Available from:
https://pure.tue.nl/ws/files/23539751/Pages_from_19320155490103.pdf

Lashina TA, Chraibi S, Shrubsole PJ, Personal lighting control for open offices. Proceedings Experiencing Light 2014 International Conference. Available from:
https://pure.tue.nl/ws/files/24134169/lashpers2014.pdf

Aarts MPJ, Chraibi S, Aries MBC, Van Loenen EJ, Wagenaar TJL (2011). Light transmittance range of glass for visual comfort in an office environment. Poster session presented at CISBAT 2011, Lausanne, Switzerland. 14-16 September 2011; 541-546.

Aarts MPJ, Chraibi S, Tenner AD (2011). Lighting design for institutionalized people with dementia symptoms. Proceedings of the light & care symposium, 10 November 2010, Eindhoven, The Netherlands. SOLG, Eindhoven, 2011; 20-24.

Patent Applications

Aliakseyeu DV, Mason JD, Meerbeek BW, Chraibi S (2018). Device apparatus cooperation via apparatus profile – US10082831B2 *granted* (2018), RU2015147168A (2017), EP2994807A2 (2016), CN105074608A (2015), and WO2014162229 (2014).

Aliakseyeu DV, Kamp ALJ, Newton PS, Rozendaal LT, Chraibi S, Van De Sluis BM, Engelen DVR (2018). Method for configuring a device in a lighting system - US20180206312A1 (2018), EP3323275A1 (2018), JP2018524777A (2018), CN107926099A (2018), and WO2017009234A1 (2017).

Aliakseyeu DV, Mason JD, Chraibi S (2017). Lighting control based on interaction with toys in play area – US9763307B2 *granted* (2017), EP3085205A1 (2016), JP2017504153A (2017), CN105940769A (2016), and WO2015092631A1 (2015).

Aliakseyeu DV, Mason JD, Meerbeek BW, Chraibi S (2018). Method of using a connected lighting system - WO2018215459A1 (2018), EP17172742 (2017).

Chen H, Calvanti DAT, Challapali KS, Chraibi S, Jia L, Rutgers AU, Yong Y, Van Hartskamp MA, Aliakseyeu DV, Hui L, Qing L, Fulong M, Mason JD, Meerbeek BW, Mills JB, De Oliveira TB, Piotrowski DJ, Yuan S, Shlayan N, Szczodrak MK, Yi Qiang Y, Zhong H, Elixmann M, Qin Z, Wianneng P, Jianfeng W, Dan J (2018). Method and apparatus for information management and control of outdoor lighting networks – US9907147B2 *granted* (2018), EP2976928A1 (2016), CN105191505A (2015), and WO2014147524A1 (2014).

Chraibi S, Lashina TA, Despenic M (2019). Lighting system – US20190090329A1 (2019), WO2017153308A1 (2017).

Chraibi S, Mason JD, Aliakseyeu DV (2018). Controlling lighting dynamics – US20170265279A1 *granted* (2018), EP3225082A1 (2017), JP2017539057A (2017), CN107006100A (2017), and WO2016083136A1 (2016).

Chraibi S, Newton PS, Mason JD, Rigot B, Aliakseyeu DV, Clout RAW, Knaapen B, Dekker T, Van De Sluis BM, Verbucken MH (2018). Apparatus for controlling lighting parameters based on time of day and/or ambient light conditions and related methods – US9936556B2 *granted* (2018), CN105814971B *granted* (2018), EP3064040A1 (2016), and WO2015063644A1 (2015).

Chraibi S, Meerbeek BW, Magielse, R, Van De Sluis BM, Aliakseyeu DV, Engelen DVR, Mason JD (2018). Lighting control apparatus – EP3284322B1 (2018), US20180132336A1 (2018), EP3284322A1 (2018), JP2018514912A (2018), CN107439056A (2017), and WO2016166023A1 (2016).

Chraibi S, Aliakseyeu DV, Mason JD (2016). Gesture based lighting control – WO2016206991A1 (2016).

Lashina TA, Teunisse J, Lenssen KMH, Chraibi S, Shrubsole PA, Aliakseyeu DV (2018). Methods and apparatus for adjusting a lighting parameter in a light management system based on user action - US9989218B2 *granted* (2018), EP2901234B1 *granted* (2018), CN104704435B *granted* (2017), and WO2014049473A1 (2014).

Mason JD, Aliakseyeu DV, Chraibi S (2019). Method of operating a control system and control system therefore – US10191536B2 *granted* (2019), US20170177073A1 (2017), JP2017512327A (2017), EP3103106A1 (2016), CN105993038A (2016), and WO2015117852A1 (2015).

Mason JD, Aliakseyeu DV, Chraibi S, Magielse, R (2018). A lighting system controller – US20180242432A1 (2018), JP2018505536A (2018), EP3257333A1 (2016), CN107211518A (2017), and WO2016128183A1 (2016),

Mason JD, Aliakseyeu DV, Chraibi S (2018). Method of obtaining gesture zone definition data for a control system based on user input – EP3170162B1 *granted* (2018) JP6242535B2 *granted* (2017), US20170205891A1 (2017), EP3170162A1 (2017), CN106663365A (2017), and WO2016009016A1 (2016).

Mason JD, Aliakseyeu DV, Meerbeek BW, Chraibi S (2017). Method and apparatus for selective illumination of an illuminated textile based on physical context – CN105393641B *granted* (2017), US9480119B2 *granted* (2016), EP3025563A1 (2016), and WO2015011605A1 (2015).

Mason JD, Aliakseyeu DV, Chraibi S (2017). Controlling lighting dynamics – US20170265269A1 (2017), EP3225081A1 (2017), JP2017535924A (2017), CN107006101A (2017), and WO2016083066A1(2016).

Mason JD, Chraibi S, Aliakseyeu DV, Meerbeek BW (2017). Lighting system control method, computer program product, wearable computing device and lighting system kit – US20170293349A1 (2017), EP3189712A1 (2017), CN106664783A (2017), and WO2016034546A1 (2016).

Magielse R, Aliakseyeu DV, Mason JD, Chraibi S (2018). Lighting Control – JP6321292B2 *granted* (2018), EP2993964B1 *granted* (2017), CN106664784A (2017), US20160072639A1 (2016), WO2016037951A1 (2016).

Magielse R, Mason JD, Aliakseyeu DV, Chraibi S (2018). Portable light source – US10076013B2 *granted* (2018), EP3254536A1 (2017), CN107211517A (2017), WO2016124390A1 (2016).

Magielse R, Aliakseyeu DV, Mason JD, Van Boven JDM, Chraibi S (2017). Lighting for games – WO2017029063A1 (2017).

Meerbeek BW, Mason JD, Aliakseyeu DW, Chraibi S (2019). Toothbrush with variable touch selection system and method of operation thereof – EP3079630B1 *granted* (2019) US10080633B2 *granted* (2018), CN105813595B *granted* (2018), EP3079630A1 (2016), and WO2015087176A1 (2015).

Meerbeek BW, Mason JD, Aliakseyeu DV, Chraibi S (2019). Method and system of communication for use in hospitals – US10241738B2 *granted* (2019), US20170315774A1 (2017), EP3215909A2 (2017), CN107077214A (2017), and WO2016071244A3 (2016).

Meerbeek BW, Mason JD, Aliakseyeu DW, Chraibi S (2018). Toothbrush with variable touch selection system and method of operation thereof – EP3079524B1 *granted* (2018), CN105813498B *granted* (2018), ES2672346T3 *granted* (2018), RU2652325C1 *granted* (2018), JP6207744B2 *granted* (2017), US20160310248A1 (2016), and WO2015087219 (2015).

Meerbeek BW, Aliakseyeu DV, Chraibi S, Mason JD (2018). A method of controlling a lighting device – US20180368239A1 (2018), WO2017102367A1 (2017).

Newton PS, Aliakseyeu DV, Van De Sluis BM, Mason JD, Chraibi S, Dekker T (2018). Lighting control apparatus and method – US10051716B2 *granted* (2018), EP3222117A1 (2017), JP2017539056A (2017), CN107004342A (2017), and WO2016079647A1 (2016).

Tiberi L, Garcia MO, Mason JD, Voncken RGH, Draaijer MHJ, Magielse, R, Shrubsole PA, Chraibi S, Aliakseyeu DV (2018). Context-related commissioning of lighting devices – US20180069720A1 (2018), EP3275128A1 (2018), JP2018518795A (2018), CN107637020A (2018), and WO2016150798A1 (2016).

Van Boven JDM, Magielse R, Aliakseyeu DV, Mason JD, Chraibi S (2017). Lighting for video games – US20180236354A1 (2018), EP3337586A1 (2017), and WO2017029103A1 (2017).

List of Figures

List of Tables

Acknowledgements

It is time for the very last part of my thesis. It has been a journey which in many ways was a personal one I was taking, but I am pleased to have shared many parts, if not all, with numerous people along the way. I would like to thank all of you, and some in special.

I want to start with my promotors. Alex, Evert, and Myriam, thank you for all our inspiring discussions, fun talks, and being my council with whom I could share my thought, discuss my approach and get advice and guidance on the paths to take. I have enjoyed our conversations and have felt privileged to have you as my promotors. Alex, you have had a vast impact on my motivation and confidence along this process. Thank you for your support and making me feel part of your group. Thank you for your confidence in my abilities, it has boosted mine. Thank you for helping me allow myself to walk a bit slower when I struggled at the end of my pregnancy. “We play using football time”, you said. I am proud of your hard work to be here to share this moment with me. Evert, thank you for your wise words in moments I tend to lose my calmness. Your constructive feedback has helped me many times to switch my perspective and see solutions. Thank you for being a solid support whenever needed. Myriam, thank you for your willingness to continue supporting me after moving >1000km north. Calls or live chats, it did not seem to matter. I appreciate all the time you took to provide me with feedback, but also your ability to help me find structure to proceed after talking to you. Thank you for the advice you gave me to overcome obstructions I thought to see and help me keep my flow.

I would also like to thank Prof. S. Altomonte, Prof. B. Eggen, Prof. H. Kort, and Prof. Y. de Kort for being part of my doctoral committee, reviewing my draft thesis and sharing your valuable feedback.

This research could not have been done without the support of Philips Research and Signify. I would like to thank management for supporting my project as part of the Philips TU/e Lighting Flagship – Spark Impuls II program; Kees van der Klauw, Greg Nelson, Jos van Haaren, and Patricia van Kemenade, but also Pieter, Bernt, and Bram in the last stage. A special thank you for Sjoerd Mentink. I wouldn’t stand here today if it wasn’t for your motivation, inspiration and huge support during the past years.

Besides management, I would like to thank my many colleagues from Philips and Signify, for all their inspiration and their lighting-, UX-, statistical-, and emotional support; Anne-Marie, Jon, Dima, Jan, Adrie, Bianca, Bernt, Doortje, Jolijn, and Elke. In special I would like to thank Tatiana and Marija. Thank you for exploring and deepening the subject together with me. I have enjoyed and appreciate our many discussions in which we challenged our design, method, and conclusions to end with work, we proudly published.

I would like to thank my colleagues of the Lighting group TU/e. Juliette, Christel, Thijs, Parisa, you have had a direct impact on my pleasure to work on my PhD. Creating an inspiring and nice “island” to work, including me in your lighting group, and being of great influence to stay on track with my planning. Thanks Marielle, for introducing the interesting discipline of lighting and experience research to me. And thank you students, with whom I have worked along the scope of this research. Patrick, Lisan, Charlotte, Vivianne, and Enrico thank you for your enthusiasm and fresh views.

A thank you to my ‘dushi’ friends from back home and my friends here in Brabant (or the Hague by now), for reinforcing my enthusiasm when a paper got published, and for your patience in times I was too occupied with my research to visit you. Thank you Jikke, for patiently reviewing my work and for not getting bored (or at least not expressing it) when discussing our PhD's during lunches, dinners, drinks or baby-dates.

This brings me to my family. Dankjewel papa en mama voor alles wat jullie me hebben meegegeven. Bedankt voor jullie eindeloze steun, trots, begrip en geduld. Pap, jij wist al dat ik dit ging doen voordat ik het zelf wist. Bedankt voor je interesse in het begrijpen van mijn werk. Mam, bedankt voor het bijspringen wanneer nodig. Wanneer ik niet meer wist waar de tijd vandaan te halen, was jij er om die te creëren. Bedankt broer en zusje, voor het delen van jullie trots, welke me wanneer nodig dat extra stukje doorzettingsvermogen gaf. Bedankt Francine voor alle steun, goede zorgen voor Rym en ons en alle gezonde maaltijden als dat er even niet meer van kwam.

Rutger, we have taken journeys of different lengths and kinds together. Typically, they did not happen sequentially. This PhD was a journey I decided to take, but I could not have done without your support. It was challenging at times, with full-time jobs, building our house, not postponing our travel desires, a wedding, a pregnancy, and a baby, all "topped off" with a PhD. Thank you for your endless patience, to allow me to take this journey. You stepped up when I needed you. You took care of Rym and me. You inspired me with your courageous attitude to meet challenges. You motivated me with your trust in my capabilities. And you shared and amplified my joy in moments of celebration. I am happy to finalize this today with you, proud and energized, for next adventure to come.

Baby Rym, I have had the special experience of sharing the final phase of my PhD with you. You are still too young to realize it, but with and because of you, I can proudly finalize this Chapter.

Bouwstenen

Bouwstenen is een publicatiereeks
van de Faculteit Bouwkunde,
Technische Universiteit Eindhoven.
Zij presenteert resultaten van
onderzoek en andere activiteiten op
het vakgebied der Bouwkunde,
uitgevoerd in het kader van deze
Faculteit.

Bouwstenen en andere proefschriften van de
TU/e zijn online beschikbaar via:
https://research.tue.nl/

Kernredactie
MTOZ

Reeds verschenen in de serie
Bouwstenen

nr 1
Elan: A Computer Model for Building Energy Design: Theory and Validation
Martin H. de Wit
H.H. Driessen
R.M.M. van der Velden

nr 2
Kwaliteit, Keuzevrijheid en Kosten: Evaluatie van Experiment Klarendal, Arnhem
J. Smeets
C. le Nobel
M. Broos
J. Frenken
A. v.d. Sanden

nr 3
Crooswijk: Van 'Bijzonder' naar 'Gewoon'
Vincent Smit
Kees Noort

nr 4
Staal in de Woningbouw
Edwin J.F. Delsing

nr 5
Mathematical Theory of Stressed Skin Action in Profiled Sheeting with Various Edge Conditions
Andre W.A.M.J. van den Bogaard

nr 6
Hoe Berekenbaar en Betrouwbaar is de Coëfficiënt k in x-ksigma en x-ks?
K.B. Lub
A.J. Bosch

nr 7
Het Typologisch Gereedschap: Een Verkennende Studie Omtrent Typologie en Omtrent de Aanpak van Typologisch Onderzoek
J.H. Luiten

nr 8
Informatievoorziening en Beheerprocessen
A. Nauta
Jos Smeets (red.)
Helga Fassbinder (projectleider)
Adrie Proveniers
J. v.d. Moosdijk

nr 9
Strukturering en Verwerking van Tijdgegevens voor de Uitvoering van Bouwwerken
ir. W.F. Schaefer
P.A. Erkelens

nr 10
Stedebouw en de Vorming van een Speciale Wetenschap
K. Doevendans

nr 11
Informatica en Ondersteuning van Ruimtelijke Besluitvorming
G.G. van der Meulen

nr 12
Staal in de Woningbouw, Korrosie-Bescherming van de Begane Grondvloer
Edwin J.F. Delsing

nr 13
Een Thermisch Model voor de Berekening van Staalplaatbetonvloeren onder Brandomstandigheden
A.F. Hamerlinck

nr 14
De Wijkgedachte in Nederland: Gemeenschapsstreven in een Stedebouwkundige Context
K. Doevendans
R. Stolzenburg

nr 15
Diaphragm Effect of Trapezoidally Profiled Steel Sheets: Experimental Research into the Influence of Force Application
Andre W.A.M.J. van den Bogaard

nr 16
Versterken met Spuit-Ferrocement: Het Mechanische Gedrag van met Spuit-Ferrocement Versterkte Gewapend Betonbalken
K.B. Lubir
M.C.G. van Wanroy

nr 17
De Tractaten van
Jean Nicolas Louis Durand
G. van Zeyl

nr 18
Wonen onder een Plat Dak:
Drie Opstellen over Enkele
Vooronderstellingen van de
Stedebouw
K. Doevendans

nr 19
Supporting Decision Making Processes:
A Graphical and Interactive Analysis of
Multivariate Data
W. Adams

nr 20
Self-Help Building Productivity:
A Method for Improving House Building
by Low-Income Groups Applied to Kenya
1990-2000
P. A. Erkelens

nr 21
De Verdeling van Woningen:
Een Kwestie van Onderhandelen
Vincent Smit

nr 22
Flexibiliteit en Kosten in het Ontwerpproces:
Een Besluitvormingondersteunend Model
M. Prins

nr 23
Spontane Nederzettingen Begeleid:
Voorwaarden en Criteria in Sri Lanka
Po Hin Thung

nr 24
Fundamentals of the Design of
Bamboo Structures
Oscar Arce-Villalobos

nr 25
Concepten van de Bouwkunde
M.F.Th. Bax (red.)
H.M.G.J. Trum (red.)

nr 26
Meaning of the Site
Xiaodong Li

nr 27
Het Woonmilieu op Begrip Gebracht:
Een Speurtocht naar de Betekenis van het
Begrip 'Woonmilieu'
Jaap Ketelaar

nr 28
Urban Environment in Developing Countries
editors: Peter A. Erkelens
George G. van der Meulen (red.)

nr 29
Stategische Plannen voor de Stad:
Onderzoek en Planning in Drie Steden
prof.dr. H. Fassbinder (red.)
H. Rikhof (red.)

nr 30
Stedebouwkunde en Stadsbestuur
Piet Beekman

nr 31
De Architectuur van Djenné:
Een Onderzoek naar de Historische Stad
P.C.M. Maas

nr 32
Conjoint Experiments and Retail Planning
Harmen Oppewal

nr 33
Strukturformen Indonesischer Bautechnik:
Entwicklung Methodischer Grundlagen
für eine 'Konstruktive Pattern Language'
in Indonesien
Heinz Frick arch. SIA

nr 34
Styles of Architectural Designing:
Empirical Research on Working Styles
and Personality Dispositions
Anton P.M. van Bakel

nr 35
Conjoint Choice Models for Urban
Tourism Planning and Marketing
Benedict Dellaert

nr 36
Stedelijke Planvorming als Co-Produktie
Helga Fassbinder (red.)

nr 37
Design Research in the Netherlands
editors: R.M. Oxman
M.F.Th. Bax
H.H. Achten

nr 38
Communication in the Building Industry
Bauke de Vries

nr 39
Optimaal Dimensioneren van
Gelaste Plaatliggers
J.B.W. Stark
F. van Pelt
L.F.M. van Gorp
B.W.E.M. van Hove

nr 40
Huisvesting en Overwinning van Armoede
P.H. Thung
P. Beekman (red.)

nr 41
Urban Habitat:
The Environment of Tomorrow
George G. van der Meulen
Peter A. Erkelens

nr 42
A Typology of Joints
John C.M. Olie

nr 43
Modeling Constraints-Based Choices
for Leisure Mobility Planning
Marcus P. Stemerding

nr 44
Activity-Based Travel Demand Modeling
Dick Ettema

nr 45
Wind-Induced Pressure Fluctuations
on Building Facades
Chris Geurts

nr 46
Generic Representations
Henri Achten

nr 47
Johann Santini Aichel:
Architectuur en Ambiguiteit
Dirk De Meyer

nr 48
Concrete Behaviour in Multiaxial
Compression
Erik van Geel

nr 49
Modelling Site Selection
Frank Witlox

nr 50
Ecolemma Model
Ferdinand Beetstra

nr 51
Conjoint Approaches to Developing
Activity-Based Models
Donggen Wang

nr 52
On the Effectiveness of Ventilation
Ad Roos

nr 53
Conjoint Modeling Approaches for
Residential Group preferences
Eric Molin

nr 54
Modelling Architectural Design
Information by Features
Jos van Leeuwen

nr 55
A Spatial Decision Support System for
the Planning of Retail and Service Facilities
Theo Arentze

nr 56
Integrated Lighting System Assistant
Ellie de Groot

nr 57
Ontwerpend Leren, Leren Ontwerpen
J.T. Boekholt

nr 58
Temporal Aspects of Theme Park Choice
Behavior
Astrid Kemperman

nr 59
Ontwerp van een Geïndustrialiseerde
Funderingswijze
Faas Moonen

nr 60
Merlin: A Decision Support System for Outdoor Leisure Planning
Manon van Middelkoop

nr 61
The Aura of Modernity
Jos Bosman

nr 62
Urban Form and Activity-Travel Patterns
Daniëlle Snellen

nr 63
Design Research in the Netherlands 2000
Henri Achten

nr 64
Computer Aided Dimensional Control in Building Construction
Rui Wu

nr 65
Beyond Sustainable Building
editors: Peter A. Erkelens
Sander de Jonge
August A.M. van Vliet
co-editor: Ruth J.G. Verhagen

nr 66
Das Globalrecyclingfähige Haus
Hans Löfflad

nr 67
Cool Schools for Hot Suburbs
René J. Dierkx

nr 68
A Bamboo Building Design Decision Support Tool
Fitri Mardjono

nr 69
Driving Rain on Building Envelopes
Fabien van Mook

nr 70
Heating Monumental Churches
Henk Schellen

nr 71
Van Woningverhuurder naar Aanbieder van Woongenot
Patrick Dogge

nr 72
Moisture Transfer Properties of Coated Gypsum
Emile Goossens

nr 73
Plybamboo Wall-Panels for Housing
Guillermo E. González-Beltrán

nr 74
The Future Site-Proceedings
Ger Maas
Frans van Gassel

nr 75
Radon transport in Autoclaved Aerated Concrete
Michel van der Pal

nr 76
The Reliability and Validity of Interactive Virtual Reality Computer Experiments
Amy Tan

nr 77
Measuring Housing Preferences Using Virtual Reality and Belief Networks
Maciej A. Orzechowski

nr 78
Computational Representations of Words and Associations in Architectural Design
Nicole Segers

nr 79
Measuring and Predicting Adaptation in Multidimensional Activity-Travel Patterns
Chang-Hyeon Joh

nr 80
Strategic Briefing
Fayez Al Hassan

nr 81
Well Being in Hospitals
Simona Di Cicco

nr 82
Solares Bauen: Implementierungs- und Umsetzungs-Aspekte in der Hochschulausbildung in Österreich
Gerhard Schuster

nr 83
Supporting Strategic Design of Workplace Environments with Case-Based Reasoning
Shauna Mallory-Hill

nr 84
ACCEL: A Tool for Supporting Concept Generation in the Early Design Phase
Maxim Ivashkov

nr 85
Brick-Mortar Interaction in Masonry under Compression
Ad Vermeltfoort

nr 86
Zelfredzaam Wonen
Guus van Vliet

nr 87
Een Ensemble met Grootstedelijke Allure
Jos Bosman
Hans Schippers

nr 88
On the Computation of Well-Structured Graphic Representations in Architectural Design
Henri Achten

nr 89
De Evolutie van een West-Afrikaanse Vernaculaire Architectuur
Wolf Schijns

nr 90
ROMBO Tactiek
Christoph Maria Ravesloot

nr 91
External Coupling between Building Energy Simulation and Computational Fluid Dynamics
Ery Djunaedy

nr 92
Design Research in the Netherlands 2005
editors: Henri Achten
Kees Dorst
Pieter Jan Stappers
Bauke de Vries

nr 93
Ein Modell zur Baulichen Transformation
Jalil H. Saber Zaimian

nr 94
Human Lighting Demands: Healthy Lighting in an Office Environment
Myriam Aries

nr 95
A Spatial Decision Support System for the Provision and Monitoring of Urban Greenspace
Claudia Pelizaro

nr 96
Leren Creëren
Adri Proveniers

nr 97
Simlandscape
Rob de Waard

nr 98
Design Team Communication
Ad den Otter

nr 99
Humaan-Ecologisch Georiënteerde Woningbouw
Juri Czabanowski

nr 100
Hambase
Martin de Wit

nr 101
Sound Transmission through Pipe Systems and into Building Structures
Susanne Bron-van der Jagt

nr 102
Het Bouwkundig Contrapunt
Jan Francis Boelen

nr 103
A Framework for a Multi-Agent Planning Support System
Dick Saarloos

nr 104
Bracing Steel Frames with Calcium Silicate Element Walls
Bright Mweene Ng'andu

nr 105
Naar een Nieuwe Houtskeletbouw
F.N.G. De Medts

nr 106 and 107
Niet gepubliceerd

nr 108
Geborgenheid
T.E.L. van Pinxteren

nr 109
Modelling Strategic Behaviour in Anticipation of Congestion
Qi Han

nr 110
Reflecties op het Woondomein
Fred Sanders

nr 111
On Assessment of Wind Comfort by Sand Erosion
Gábor Dezsö

nr 112
Bench Heating in Monumental Churches
Dionne Limpens-Neilen

nr 113
RE. Architecture
Ana Pereira Roders

nr 114
Toward Applicable Green Architecture
Usama El Fiky

nr 115
Knowledge Representation under Inherent Uncertainty in a Multi-Agent System for Land Use Planning
Liying Ma

nr 116
Integrated Heat Air and Moisture Modeling and Simulation
Jos van Schijndel

nr 117
Concrete Behaviour in Multiaxial Compression
J.P.W. Bongers

nr 118
The Image of the Urban Landscape
Ana Moya Pellitero

nr 119
The Self-Organizing City in Vietnam
Stephanie Geertman

nr 120
A Multi-Agent Planning Support System for Assessing Externalities of Urban Form Scenarios
Rachel Katoshevski-Cavari

nr 121
Den Schulbau Neu Denken, Fühlen und Wollen
Urs Christian Maurer-Dietrich

nr 122
Peter Eisenman Theories and Practices
Bernhard Kormoss

nr 123
User Simulation of Space Utilisation
Vincent Tabak

nr 125
In Search of a Complex System Model
Oswald Devisch

nr 126
Lighting at Work:
Environmental Study of Direct Effects of Lighting Level and Spectrum on Psycho-Physiological Variables
Grazyna Górnicka

nr 127
Flanking Sound Transmission through Lightweight Framed Double Leaf Walls
Stefan Schoenwald

nr 128
Bounded Rationality and Spatio-Temporal Pedestrian Shopping Behavior
Wei Zhu

nr 129
Travel Information:
Impact on Activity Travel Pattern
Zhongwei Sun

nr 130
Co-Simulation for Performance Prediction of Innovative Integrated Mechanical Energy Systems in Buildings
Marija Trčka

nr 131
Niet gepubliceerd

nr 132
Architectural Cue Model in Evacuation Simulation for Underground Space Design
Chengyu Sun

nr 133
Uncertainty and Sensitivity Analysis in Building Performance Simulation for Decision Support and Design Optimization
Christina Hopfe

nr 134
Facilitating Distributed Collaboration in the AEC/FM Sector Using Semantic Web Technologies
Jacob Beetz

nr 135
Circumferentially Adhesive Bonded Glass Panes for Bracing Steel Frame in Façades
Edwin Huveners

nr 136
Influence of Temperature on Concrete Beams Strengthened in Flexure with CFRP
Ernst-Lucas Klamer

nr 137
Sturen op Klantwaarde
Jos Smeets

nr 139
Lateral Behavior of Steel Frames with Discretely Connected Precast Concrete Infill Panels
Paul Teewen

nr 140
Integral Design Method in the Context of Sustainable Building Design
Perica Savanović

nr 141
Household Activity-Travel Behavior: Implementation of Within-Household Interactions
Renni Anggraini

nr 142
Design Research in the Netherlands 2010
Henri Achten

nr 143
Modelling Life Trajectories and Transport Mode Choice Using Bayesian Belief Networks
Marloes Verhoeven

nr 144
Assessing Construction Project Performance in Ghana
William Gyadu-Asiedu

nr 145
Empowering Seniors through Domotic Homes
Masi Mohammadi

nr 146
An Integral Design Concept for Ecological Self-Compacting Concrete
Martin Hunger

nr 147
Governing Multi-Actor Decision Processes in Dutch Industrial Area Redevelopment
Erik Blokhuis

nr 148
A Multifunctional Design Approach for Sustainable Concrete
Götz Hüsken

nr 149
Quality Monitoring in Infrastructural Design-Build Projects
Ruben Favié

nr 150
Assessment Matrix for Conservation of Valuable Timber Structures
Michael Abels

nr 151
Co-simulation of Building Energy Simulation and Computational Fluid Dynamics for Whole-Building Heat, Air and Moisture Engineering
Mohammad Mirsadeghi

nr 152
External Coupling of Building Energy Simulation and Building Element Heat, Air and Moisture Simulation
Daniel Cóstola

nr 153
Adaptive Decision Making In Multi-Stakeholder Retail Planning
Ingrid Janssen

nr 154
Landscape Generator
Kymo Slager

nr 155
Constraint Specification in Architecture
Remco Niemeijer

nr 156
A Need-Based Approach to Dynamic Activity Generation
Linda Nijland

nr 157
Modeling Office Firm Dynamics in an Agent-Based Micro Simulation Framework
Gustavo Garcia Manzato

nr 158
Lightweight Floor System for Vibration Comfort
Sander Zegers

nr 159
Aanpasbaarheid van de Draagstructuur
Roel Gijsbers

nr 160
'Village in the City' in Guangzhou, China
Yanliu Lin

nr 161
Climate Risk Assessment in Museums
Marco Martens

nr 162
Social Activity-Travel Patterns
Pauline van den Berg

nr 163
Sound Concentration Caused by Curved Surfaces
Martijn Vercammen

nr 164
Design of Environmentally Friendly Calcium Sulfate-Based Building Materials: Towards an Improved Indoor Air Quality
Qingliang Yu

nr 165
Beyond Uniform Thermal Comfort on the Effects of Non-Uniformity and Individual Physiology
Lisje Schellen

nr 166
Sustainable Residential Districts
Gaby Abdalla

nr 167
Towards a Performance Assessment Methodology using Computational Simulation for Air Distribution System Designs in Operating Rooms
Mônica do Amaral Melhado

nr 168
Strategic Decision Modeling in Brownfield Redevelopment
Brano Glumac

nr 169
Pamela: A Parking Analysis Model for Predicting Effects in Local Areas
Peter van der Waerden

nr 170
A Vision Driven Wayfinding Simulation-System Based on the Architectural Features Perceived in the Office Environment
Qunli Chen

nr 171
Measuring Mental Representations Underlying Activity-Travel Choices
Oliver Horeni

nr 172
Modelling the Effects of Social Networks on Activity and Travel Behaviour
Nicole Ronald

nr 173
Uncertainty Propagation and Sensitivity Analysis Techniques in Building Performance Simulation to Support Conceptual Building and System Design
Christian Struck

nr 174
Numerical Modeling of Micro-Scale Wind-Induced Pollutant Dispersion in the Built Environment
Pierre Gousseau

nr 175
Modeling Recreation Choices
over the Family Lifecycle
Anna Beatriz Grigolon

nr 176
Experimental and Numerical Analysis of
Mixing Ventilation at Laminar, Transitional
and Turbulent Slot Reynolds Numbers
Twan van Hooff

nr 177
Collaborative Design Support:
Workshops to Stimulate Interaction and
Knowledge Exchange Between Practitioners
Emile M.C.J. Quanjel

nr 178
Future-Proof Platforms for Aging-in-Place
Michiel Brink

nr 179
Motivate:
A Context-Aware Mobile Application for
Physical Activity Promotion
Yuzhong Lin

nr 180
Experience the City:
Analysis of Space-Time Behaviour and
Spatial Learning
Anastasia Moiseeva

nr 181
Unbonded Post-Tensioned Shear Walls of
Calcium Silicate Element Masonry
Lex van der Meer

nr 182
Construction and Demolition Waste
Recycling into Innovative Building Materials
for Sustainable Construction in Tanzania
Mwita M. Sabai

nr 183
Durability of Concrete
with Emphasis on Chloride Migration
Przemysław Spiesz

nr 184
Computational Modeling of Urban
Wind Flow and Natural Ventilation Potential
of Buildings
Rubina Ramponi

nr 185
A Distributed Dynamic Simulation
Mechanism for Buildings Automation
and Control Systems
Azzedine Yahiaoui

nr 186
Modeling Cognitive Learning of Urban
Networks in Daily Activity-Travel Behavior
Şehnaz Cenani Durmazoğlu

nr 187
Functionality and Adaptability of Design
Solutions for Public Apartment Buildings
in Ghana
Stephen Agyefi-Mensah

nr 188
A Construction Waste Generation Model
for Developing Countries
Lilliana Abarca-Guerrero

nr 189
Synchronizing Networks:
The Modeling of Supernetworks for
Activity-Travel Behavior
Feixiong Liao

nr 190
Time and Money Allocation Decisions
in Out-of-Home Leisure Activity Choices
Gamze Zeynep Dane

nr 191
How to Measure Added Value of CRE and
Building Design
Rianne Appel-Meulenbroek

nr 192
Secondary Materials in Cement-Based
Products:
Treatment, Modeling and Environmental
Interaction
Miruna Florea

nr 193
Concepts for the Robustness Improvement
of Self-Compacting Concrete:
Effects of Admixtures and Mixture
Components on the Rheology and Early
Hydration at Varying Temperatures
Wolfram Schmidt

nr 194
Modelling and Simulation of Virtual Natural Lighting Solutions in Buildings
Rizki A. Mangkuto

nr 195
Nano-Silica Production at Low Temperatures from the Dissolution of Olivine - Synthesis, Tailoring and Modelling
Alberto Lazaro Garcia

nr 196
Building Energy Simulation Based Assessment of Industrial Halls for Design Support
Bruno Lee

nr 197
Computational Performance Prediction of the Potential of Hybrid Adaptable Thermal Storage Concepts for Lightweight Low-Energy Houses
Pieter-Jan Hoes

nr 198
Application of Nano-Silica in Concrete
George Quercia Bianchi

nr 199
Dynamics of Social Networks and Activity Travel Behaviour
Fariya Sharmeen

nr 200
Building Structural Design Generation and Optimisation including Spatial Modification
Juan Manuel Davila Delgado

nr 201
Hydration and Thermal Decomposition of Cement/Calcium-Sulphate Based Materials
Ariën de Korte

nr 202
Republiek van Beelden:
De Politieke Werkingen van het Ontwerp in Regionale Planvorming
Bart de Zwart

nr 203
Effects of Energy Price Increases on Individual Activity-Travel Repertoires and Energy Consumption
Dujuan Yang

nr 204
Geometry and Ventilation:
Evaluation of the Leeward Sawtooth Roof Potential in the Natural Ventilation of Buildings
Jorge Isaac Perén Montero

nr 205
Computational Modelling of Evaporative Cooling as a Climate Change Adaptation Measure at the Spatial Scale of Buildings and Streets
Hamid Montazeri

nr 206
Local Buckling of Aluminium Beams in Fire Conditions
Ronald van der Meulen

nr 207
Historic Urban Landscapes:
Framing the Integration of Urban and Heritage Planning in Multilevel Governance
Loes Veldpaus

nr 208
Sustainable Transformation of the Cities:
Urban Design Pragmatics to Achieve a Sustainable City
Ernesto Antonio Zumelzu Scheel

nr 209
Development of Sustainable Protective Ultra-High Performance Fibre Reinforced Concrete (UHPFRC):
Design, Assessment and Modeling
Rui Yu

nr 210
Uncertainty in Modeling Activity-Travel Demand in Complex Uban Systems
Soora Rasouli

nr 211
Simulation-based Performance Assessment of Climate Adaptive Greenhouse Shells
Chul-sung Lee

nr 212
Green Cities:
Modelling the Spatial Transformation of the Urban Environment using Renewable Energy Technologies
Saleh Mohammadi

nr 213
A Bounded Rationality Model of Short and Long-Term Dynamics of Activity-Travel Behavior
Ifigeneia Psarra

nr 214
Effects of Pricing Strategies on Dynamic Repertoires of Activity-Travel Behaviour
Elaheh Khademi

nr 215
Handstorm Principles for Creative and Collaborative Working
Frans van Gassel

nr 216
Light Conditions in Nursing Homes: Visual Comfort and Visual Functioning of Residents
Marianne M. Sinoo

nr 217
Woonsporen: De Sociale en Ruimtelijke Biografie van een Stedelijk Bouwblok in de Amsterdamse Transvaalbuurt
Hüseyin Hüsnü Yegenoglu

nr 218
Studies on User Control in Ambient Intelligent Systems
Berent Willem Meerbeek

nr 219
Daily Livings in a Smart Home: Users' Living Preference Modeling of Smart Homes
Erfaneh Allameh

nr 220
Smart Home Design: Spatial Preference Modeling of Smart Homes
Mohammadali Heidari Jozam

nr 221
Wonen: Discoursen, Praktijken, Perspectieven
Jos Smeets

nr 222
Personal Control over Indoor Climate in Offices: Impact on Comfort, Health and Productivity
Atze Christiaan Boerstra

nr 223
Personalized Route Finding in Multimodal Transportation Networks
Jianwe Zhang

nr 224
The Design of an Adaptive Healing Room for Stroke Patients
Elke Daemen

nr 225
Experimental and Numerical Analysis of Climate Change Induced Risks to Historic Buildings and Collections
Zara Huijbregts

nr 226
Wind Flow Modeling in Urban Areas Through Experimental and Numerical Techniques
Alessio Ricci

nr 227
Clever Climate Control for Culture: Energy Efficient Indoor Climate Control Strategies for Museums Respecting Collection Preservation and Thermal Comfort of Visitors
Rick Kramer

nr 228
Fatigue Life Estimation of Metal Structures Based on Damage Modeling
Sarmediran Silitonga

nr 229
A multi-agents and occupancy based strategy for energy management and process control on the room-level
Timilehin Moses Labeodan

nr 230
Environmental assessment of Building Integrated Photovoltaics: Numerical and Experimental Carrying Capacity Based Approach
Michiel Ritzen

nr 231
Performance of Admixture and Secondary Minerals in Alkali Activated Concrete: Sustaining a Concrete Future
Arno Keulen

nr 232
World Heritage Cities and Sustainable Urban Development:
Bridging Global and Local Levels in Monitoring the Sustainable Urban Development of World Heritage Cities
Paloma C. Guzman Molina

nr 233
Stage Acoustics and Sound Exposure in Performance and Rehearsal Spaces for Orchestras:
Methods for Physical Measurements
Remy Wenmaekers

nr 234
Municipal Solid Waste Incineration (MSWI) Bottom Ash:
From Waste to Value Characterization, Treatments and Application
Pei Tang

nr 235
Large Eddy Simulations Applied to Wind Loading and Pollutant Dispersion
Mattia Ricci

nr 236
Alkali Activated Slag-Fly Ash Binders:
Design, Modeling and Application
Xu Gao

nr 237
Sodium Carbonate Activated Slag:
Reaction Analysis, Microstructural Modification & Engineering Application
Bo Yuan

nr 238
Shopping Behavior in Malls
Widiyani

nr 239
Smart Grid-Building Energy Interactions:
Demand Side Power Flexibility in Office Buildings
Kennedy Otieno Aduda

nr 240
Modeling Taxis Dynamic Behavior in Uncertain Urban Environments
Zheng Zhong

nr 241
Gap-Theoretical Analyses of Residential Satisfaction and Intention to Move
Wen Jiang

nr 242
Travel Satisfaction and Subjective Well-Being:
A Behavioral Modeling Perspective
Yanan Gao

nr 243
Building Energy Modelling to Support the Commissioning of Holistic Data Centre Operation
Vojtech Zavrel

nr 244
Regret-Based Travel Behavior Modeling:
An Extended Framework
Sunghoon Jang

nr 245
Towards Robust Low-Energy Houses:
A Computational Approach for Performance Robustness Assessment using Scenario Analysis
Rajesh Reddy Kotireddy

nr 246
Development of sustainable and functionalized inorganic binder-biofiber composites
Guillaume Doudart de la Grée

nr 247
A Multiscale Analysis of the Urban Heat Island Effect: From City Averaged Temperatures to the Energy Demand of Individual Buildings
Yasin Toparlar

nr 248
Design Method for Adaptive Daylight Systems for buildings covered by large (span) roofs
Florian Heinzelmann

nr 249
Hardening, high-temperature resistance and acid resistance of one-part geopolymers
Patrick Sturm

nr 250
Effects of the built environment on dynamic repertoires of activity-travel behaviour
Aida Pontes de Aquino

nr 251
Modeling for auralization of urban environments: Incorporation of directivity in sound propagation and analysis of a framework for auralizing a car pass-by
Fotis Georgiou

nr 252
Wind Loads on Heliostats and Photovoltaic Trackers
Andreas Pfahl

nr 253
Approaches for computational performance optimization of innovative adaptive façade concepts
Roel Loonen

nr 254
Multi-scale FEM-DEM Model for Granular Materials: Micro-scale boundary conditions, Statics, and Dynamics
Jiadun Liu

nr 255
Bending Moment - Shear Force Interaction of Rolled I-Shaped Steel Sections
Rianne Willie Adriana Dekker

nr 256
Paralympic tandem cycling and handcycling: Computational and wind tunnel analysis of aerodynamic performance
Paul Fionn Mannion

nr 257
Experimental characterization and numerical modelling of 3D printed concrete: Controlling structural behaviour in the fresh and hardened state
Robert Johannes Maria Wolfs

nr 258
Requirement checking in the building industry: Enabling modularized and extensible requirement checking systems based on semantic web technologies
Chi Zhang

nr 259
A Sustainable Industrial Site Redevelopment Planning Support System
Tong Wang

nr 260
Efficient storage and retrieval of detailed building models: Multi-disciplinary and long-term use of geometric and semantic construction information
Thomas Ferdinand Krijnen

nr 261
The users' value of business center concepts for knowledge sharing and networking behavior within and between organizations
Minou Weijs-Perrée

nr 262
Characterization and improvement of aerodynamic performance of vertical axis wind turbines using computational fluid dynamics (CFD)
Abdolrahim Rezaeiha

nr 263
In-situ characterization of the acoustic impedance of vegetated roofs
Chang Liu

nr 264
Occupancy-based lighting control: Developing an energy saving strategy that ensures office workers' comfort
Christel de Bakker

nr 265
Stakeholders-Oriented Spatial Decision Support System
Cahyono Susetyo

nr 266
Climate-induced damage in oak museum objects
Rianne Aleida Luimes

nr 267
nog niet bekend / gepubliceerd

nr 268
Modelling and Measuring Quality of Urban Life: Housing, Neighborhood, Transport and Job
Lida Aminian

nr 269
nog niet bekend / gepubliceerd

nr 270
Numerical modeling for urban sound propagation: developments in wave-based and energy-based methods
Raúl Pagán Muñoz

Spending a large majority of our time indoors makes the indoor environmental conditions important determinants of our satisfaction and wellbeing. Over the last decades, lighting has established itself as a recognized influencer of people's wellbeing in living and working environments. While poor design can cause discomfort, the right implementations can elevate satisfaction, improve mood, and influence performance. The office as functional workspace has started giving way to spaces designed to engage and inspire, resulting in an increase of open office environments. The shared character of the open office does, however, create challenges to cater to the individual's wellbeing in these multi-user spaces.

In this thesis, wellbeing is addressed by improving the users' experience of the lighting environment. Research is presented showing that in shared office spaces, like open plan offices, personal control over lighting can improve the users' appreciation of office lighting. The proposition of personal control can be further optimized when the preferences of users in the office are considered and integrated in the behaviour or feedback of the system. By careful consideration of the brightness of the office walls as well as the speed by which dimming is applied, the risk of conflict occurrence can be limited. Technological developments allow for state-of-the-art systems, that can support building owners or employers in optimizing their buildings, to increase efficiency and limit costs. To utilize these advanced systems to their full potential, it is important to keep considering and consulting the users of the buildings.

DEPARTMENT OF THE BUILT ENVIRONMENT

EINDHOVEN
UNIVERSITY OF
TECHNOLOGY