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Lighting preference profiles of users in an open office environment

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ABSTRACT

Offices are transforming into multi-user, open space environments to stimulate interaction between people and optimize the usage of 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. This paper proposes a first method for modelling lighting preference profiles of users based on their control behaviour and preference information. Based on objective measurements and subjective data obtained in two field studies, users can be profiled based on their control behaviour, regarding characteristics as activeness, dominance, lighting tolerance, and dimming level preference. The results show significant differences between lighting preference profiles of users. This paper also proposes a first method for discovering and triggering submissive users to express their preferences in order to derive their profiles as accurate as possible. This will help to secure users' comfort by offering satisfying lighting conditions to their preference. By knowing the lighting preference profiles of users, the probability of conflict between users can be predicted and minimized.

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 in popularity [1]. Employees make transitions more often between work modes at their desks and between locations compared to traditional ways of working [2,3,4]. Standards provide lighting recommendations to ensure a comfortably lit office environment [5,6], 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.

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 [7] evaluated the preferred lighting conditions of 94 participants when performing office tasks. The study showed that the range of the individual lighting preferences, corresponding to the horizontal illuminance, was between 83 and 725 lx. In another laboratory study of Newsham and colleagues [8], participants worked in a mock-up office for one day. They had no control over lighting until the latter half of the afternoon. Participants chose desktop illuminances ranging from 116 lx up to the maximum achievable 1478 lx. In the laboratory study performed by Boyce et al. [9] 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 to 1230 lx for the larger and from 80 to 630 lx for the smaller control range. In a later performed study by Boyce et al. [10], 57 temporary office workers spent a day in an office with the freedom to adjust the lighting of the cubicles they occupied. The

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study showed individual preferences to range from 252 to 1176 lx. A longitudinal field study of Moore et al. [11] included 45 office workers in 4 different buildings in UK, where occupants were able to vary the illuminance on their workplace. The study showed that the mean daily workplace illuminance was 288 lx, with individual averages ranging from 91 lx to 770 lx.

Besides the varying horizontal illuminances, the different facilities in which the experiments were conducted also resulted in varying luminance distributions. The luminance distributions are linked to the brightness perception, and will influence the preference of users. The horizontal illuminance is used as an indicator for the given dimming level of the luminaire, which creates the individually preferred luminance distribution for a given situation. 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 demonstrated that the maximum amount of occupants that would be within 100 lx of their preferred illuminance is only around 65% [10]. 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 environmental conditions [8,12–19], with lighting quantity and quality [20], mood, improved motivation and vigilance [21], and indirect positive effects on their productivity [8,20,22]. Besides, occupants who have more opportunities to adapt their environments to their own needs will less likely experience discomfort [22]. On the contrary, having a workspace without some degree of control over the environment, leads to increased discomfort and stress [23]. Therefore, personal control for office lighting is believed to enhance users' satisfaction and comfort in modern office buildings.

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 impossible 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 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. showed that occupants become increasingly reluctant to make changes to the lighting as control groups become larger [24]. The researchers suggested that the control group size should be the smallest possible, to enhance user satisfaction and maximize the benefits of lighting control, while equally empowering users. The follow-up study [19] showed that even when sharing controls, the majority of users experienced the benefit of having controls. Satisfaction with lighting quality and quantity was rated higher than in situations without control. In a field study evaluating personal control in an open office space [25], similar results for improved lighting quality and quantity were demonstrated. 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. 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 [7–11]. In interviews, users who participated in the performed preference study [25] 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 in the study of O'Brien and Gunay [22], a conflict avoiding behaviour was observed in the study of Chraibi et al. [25]. O'Brien and Gunay showed that people are profoundly affected by the presence of others to take actions that might cause discomfort to colleagues. People have different personalities which 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.

1.3. Research motivation

Personal characteristics are believed to have an influence on users' preferred and selected lighting, when given a choice. A number of studies evaluated occupants' lighting preference and the effect of their personality on interaction with lighting systems [26,27]. Newsham et al. [28] 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 [9] also showed that there is a large difference between different occupants regarding their control behaviour. Some people adjust illuminance levels a little, while others adjust illuminance levels over the whole range available. 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 [22]. People who experience conflict have decreased satisfaction with lighting quality and are more likely to avoid using controls than those who do not experience conflict [29]. This study of Moore and colleagues also showed that stronger personalities dominate in conflict situations.

This paper presents insights gained from analysing light preference data of the users, obtained in two field studies. The authors show that users can be profiled 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 taken into account. The preference of an intolerant user asks for