Building and Environment 103 (2016) 70–85

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Automated blinds with light feedback to increase occupant satisfaction and energy saving

B.W. Meerbeek [a, b, *], C. de Bakker [b], Y.A.W. de Kort [b, c], E.J. van Loenen [a, b], T. Bergman [a]

[a] Philips Lighting Research, High Tech Campus 7, 5656 AE Eindhoven, The Netherlands
[b] Intelligent Lighting Institute, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
[c] Human Technology Interaction, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

ARTICLE INFO

Article history:
Received 12 January 2016
Received in revised form
29 March 2016
Accepted 4 April 2016
Available online 6 April 2016

Keywords:
Building automation
User control
Daylight
Blinds
Technology acceptance
User interface
Virtual window

ABSTRACT

With the increase of building automation in the work environment, there is a risk that occupants lose their sense of control when decisions on environmental aspects such as temperature, electric lighting, and daylight are made by technology. This paper reports two experiments in which we investigated the effect of the level automation and the type of system expressiveness on users' satisfaction with an automated blinds system installed on a virtual window. An expressive interface was designed to communicate the status and intentions of the blinds system to the building occupants. The results show that the addition of the expressive interface increased user satisfaction compared to the original system. Moreover, users made less corrections after automatic blind adjustments and adherence to the system suggestions increased. These results demonstrate the potential of expressive interfaces to increase user's acceptance of automated blinds and thereby realizing the anticipated energy savings.

1. Introduction

1.1. Perceived control in automated office buildings

The increasing attention for energy efficient buildings combined with technological advances in sensors, processing power, lighting, and networks drive the development of so called ‘Smart Buildings’. Simple forms of building intelligence such as occupancy sensing or daylight-based dimming are already common practice. There are clear economical drivers for building automation. For example, energy and cost savings can be realized by automatically switching off the light when people are not in a room or by dimming the electric light if sufficient daylight is available. Building automation should not only result in energy and cost savings, but also make sure that occupants are satisfied with and feel in control of their working environment. User acceptance is essential for successful adoption of building automation technologies, but at the same time difficult to achieve. A balance between energy efficiency and occupant comfort needs to be found, ensuring that people feel comfortable and productive at their workplace while preserving the energy saving potential of building automation technologies.

Both in the domain of technology acceptance and in the domain of the built environment, a sense of control is generally recognized as an important factor influencing comfort and satisfaction (e.g. [2,4,13]). Perceived control is included in technology acceptance models and user satisfaction measures (e.g. [31]). Veitch [32] describes perception of control as an important psychological process that influences perceived lighting quality and satisfaction with the working environment. In her study, people with dimming control reported higher ratings of lighting quality, environmental satisfaction, self-rated productivity, and even showed more sustained motivation and improved performance on a measure of attention. Similarly, Newsham and colleagues [21] showed in a laboratory study that the provision of dimming control for a lighting system resulted in improvements on several factors including mood, satisfaction with the environment, and self-assessed productivity. Lee and Brand [14] have investigated the effect of control over the office workspace on perceptions of the work environment and work outcomes. Based on a questionnaire study among more than 200 office workers, they concluded that having personal control over the physical working environment positively influences both job satisfaction and group cohesiveness.

* Corresponding author. Philips Lighting Research, High Tech Campus 7, 5656 AE Eindhoven, The Netherlands.
E-mail address: bernt.meerbeek@philips.com (B.W. Meerbeek).

http://dx.doi.org/10.1016/j.buildenv.2016.04.002
0360-1323/

With the increase of building automation in the work environment, there is a risk that occupants lose their sense of control when decisions on environmental aspects such as temperature, electric lighting, and daylight are made by technology.

1.2. Automatic and manual blinds operations

Previous research on automatic and manual blind systems in the work environment indicates the importance of appropriate daylight control for energy saving and user comfort. Several studies investigated the use of manual blinds and show that people do not regularly change the blinds positions [11,5,23,26]. People generally lower the blinds to block direct sunlight, but often forget to retract them. If people retract blinds, they mainly do this to increase daylight entrance or to create a view [6]. Interestingly however, Reinhart and Voss [28] found that in 88% of the cases when the blinds were lowered automatically, people manually raised them within 15 min, indicating a low acceptance of automatic blind adjustments. Guillemin and Morel [7] developed and evaluated a self-adaptive integrated system for energy and comfort management in buildings, in which the blinds control system was optimized for visual comfort if a user was present and for thermal comfort in absence of a user. Although the solution demonstrated its potential for reducing the energy consumption, the questionnaire results showed that users quickly got angry at the automatic system when it did not take into account their wishes. Vine and colleagues [33] investigated office workers' response to an automated interior venetian blind system with a linked electric lighting system. In a pilot study, 14 participants experienced three modes of operation during sessions of one hour per mode. The three modes varied in degree of control that was available to the user. The general levels of satisfaction were similar among the three modes of operation, although there seemed to be a tendency that in the manual control mode participants were more satisfied with the lighting conditions than in the automatic user control mode. Participants seemed to be least satisfied with the automatic mode. However, the sample size and time frame of the study, as well as the differences found, are too small to make conclusive statements about the effect of control mode on satisfaction with the lighting. Sadeghi and colleagues [29] performed a comparative study on occupant interactions with shading and lighting systems using four different control interfaces, including a fully automatic system, an automatic system with manual overrides via a remote control, manual control via a wall switch, and manual control via a web interface. The fully automatic system resulted in the lowest scores on comfort. Comfort votes were increased when manual override was possible or when manual control was offered via the web interface or wall switch. They further emphasize the importance of accessibility of the controls. Similarly, Bakker and colleagues [2] showed that having the possibility to manually overrule the automated facade leads to higher user satisfaction with light levels on the work plane and in the room. Based on a literature review, Galasiu and Veitch [6] concluded that photo-controlled lighting systems are most widely accepted when there is individual override control. Integrated control for both lighting and shading can be acceptable, but are most widely accepted when a degree of manual control is provided. Another literature review on dynamically controlled shading systems confirms the importance of simple manual controls for acceptance of automated shading systems [12]. Although these cited studies clearly show the importance of personal control for occupants' comfort, several studies highlighted that occupant control of blinds and lighting can significantly increase energy demand in a building [8,9]. In recent work, Meerbeek and colleagues [20] reported a field study in 40 Dutch offices in which they monitored the blinds usage of an automated blinds system over a period of 20 weeks. The results showed that a majority of the building occupants (77.5%) switched off the automatic mode of the blinds system permanently. Simulation results indicated that this significantly impacts the energy consumption in the building. The estimated total daily average energy consumption for heating and cooling was significantly lower for occupants using the automatic mode than for manual users [20]. One of the reasons for switching off the automatic mode was that occupants did not understand why the blinds were moving up or down. They felt this was often occurring at the wrong moments.

1.3. Expressive interface for automated systems

To help people understand and accept the behaviour of automated systems, appropriate communication from the system towards the users is deemed a crucial factor. This communication might be provided by an expressive interface which provides information to the end-user about the internal reasoning, intentions, and actions of the automated system. In particular when tasks are only partially automated, “it is essential that each party, human and machine, know what the other is doing and what is intended.” [22]. Often, expressive interfaces come in a human-like representation as people are wired to communicate with other people and experts in interpreting verbal and non-verbal signals from other human beings. Experiments have shown that people are inclined to attribute human characteristics to technology while interacting with it and to perceive the systems as social actors [27]. It has been found in other domains that people tend to attribute personality traits to automated systems [19]. This attributed system personality might help in the interaction between users and technology as it allows people to form a conceptual model of the system. It channels behaviour, beliefs, and intentions into a cohesive, consistent set of behaviours [22].

Expressive interfaces might also affect users' perception of control. Generally, information, choice and predictability are the three prominent factors that are found to influence perceived level of control [30]. In the context of this study, the expressive interface might provide the user with information related to the blinds status or outside conditions and give the user options to choose from (e.g. lowering or raising the blinds). In addition, the expressive interface might help users to predict the automatic behaviour of the system, for example by signalling an automatic blind change before it is effectuated.

1.4. Research questions

In this study we investigate the user satisfaction and actual usage of an automated blinds system with an expressive interface. More specifically, we research the effect of the level automation and the type of system expressiveness on users' satisfaction with and usage of the blinds system installed on a virtual window with LED spot to mimic sunlight. Two experiments are conducted to address this research question. In the first experiment ($N = 48$), three levels of automation and two types of expressiveness are compared in a controlled mixed design user study in a laboratory setting to find their main effects on user satisfaction and blinds usage as well as the interaction effects between level of automation and type of expressiveness (Section 3). In the second experiment ($N = 24$), two types of expressiveness with the same level of automation are compared, again through a user study in a laboratory setting, to zoom in on the effects of the type of expressiveness on satisfaction and usage (Section 4). But first, Section 2 describes the design of the expressive interface and the levels of automation that were tested in these two experiments.