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Building automation and perceived control: A field study on motorized exterior blinds in Dutch offices

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ABSTRACT

As a result of the technological advances and increasing focus on energy efficient buildings, simple forms of building automation including automatic motorized blinds systems found their ways into today's office environments. In a five-month field study, qualitative and quantitative methods were used to investigate how office workers in 40 offices experience and use automatically controlled exterior venetian blinds with options for manual override and switching off the automatic mode. In total, 3433 blinds adjustments (average of 0.86 per office per day) were recorded, of which 73.6% was initiated by the user. Significant correlations between weather parameters and blind adjustments were found, including sunshine duration and user-triggered lowering of blinds ($R = 0.354$), cloud cover and user-triggered lowering of the blinds ($R = -0.281$), and outside temperature and user-triggered raising of blinds ($R = -0.266$). Four blinds usage profiles were identified and the underlying motivations for the different users were described. In the majority of offices, the automatic mode was switched off.

1. Introduction

1.1. Comfort 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'. In line with the ambient intelligence vision, it is expected that office buildings will evolve into 'ambient intelligent' office environments [1]. Technology will be embedded into the office environment, aware of the context, personalized to individuals, and adaptive and anticipatory to their needs. This vision is starting to become a reality in today's office buildings. Simple forms of building intelligence such as occupancy sensing or daylight-based dimming are already common practice. User acceptance of this intelligence is a sine-qua-non for successful adoption of building automation technologies, but at the same time difficult to achieve.

There are clear economical drivers for ambient intelligent office environments. 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. Such intelligent behavior 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. If decisions are based solely on economic criteria such as energy saving, the resulting conditions might not be beneficial for the comfort of occupants. A balance between energy efficiency and occupant comfort needs to be found.

As a large part of the population spends a significant part of the day in an office environment, it is not surprising to see an increasing awareness of user comfort in office buildings. Although comfort is a subjective concept, much research has been done on objective determinants and measures of comfort. Many aspects have been identified that influence the perception of comfort in offices, including environmental aspects (e.g. building characteristics, climate), social aspects (e.g. relationships with colleagues), and personal aspects (e.g. gender, age) [3]. It is unclear how all of these different aspects relate to each other and contribute to an overall perception of comfort, but studies have shown the importance of separate environmental aspects such as daylight and electric lighting on the perception of comfort. People who are more

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satisfied with their lighting rate the space as more attractive, are happier, and are more comfortable and satisfied with their work environment and their work [4]. Another important factor that influences an individual's comfort in the work environment is the feeling of control.

1.2. Control

Decades of research in sociology and psychology have demonstrated that a sense of control is a robust predictor of physical and mental wellbeing [19]. Many different constructs of control appear in literature. It is outside the scope of this paper to discuss the various constructs of control in detail, but a short introduction is necessary to understand the concept of control as it is being used in this study. The 'locus of control' is probably the most studied construct related to control and refers to "the degree to which persons expect that a reinforcement or an outcome of their behavior is contingent on their own behavior or personal characteristics versus the degree to which persons expect that the reinforcement or outcome is a function of chance, luck, or fate, is under the control of powerful others, or is simply unpredictable" [18, p. 1]. People with an internal locus of control believe that one has control over the outcomes of events, while people with an external locus of control tend to attribute outcomes of events to external circumstances. An integrative framework for constructs of control is provided by Skinner [19]. She distinguishes between objective (or actual) control, subjective control, and experiences of control. Objective control is "the extent of actual control present, as represented by some normatively appropriate assessment of the action–outcome relationship". Subjective control refers to "an individual's beliefs about how much control is available". The experience of control refers to "an individual's feelings as he or she is interacting with the environment while attempting to produce a desired or prevent an undesired outcome". For the purpose of this study, we distinguish between the actual control over the blinds that is available to an individual (i.e. 'automatic mode' with manual override vs. 'manual mode' in which the automatic mode is switched off) and the experienced level of control (i.e. the feeling of being able to adjust the blinds to the desired state).

Both in the domain of technology acceptance and the domain of the built environment, a sense of control is generally recognized as in important factor influencing comfort and satisfaction. Norman [14] investigated the acceptance of agent technology – intelligent systems with some degree of autonomy – and found a positive relationship between the feeling of control and people's attitude towards the technology. Perceived control is often included as a factor in technology acceptance models and user satisfaction measures (e.g. Venkatesh et al. [23]). Veitch [21] 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 et al. [13] 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. Interestingly, Veitch and Gifford [22] demonstrated through a controlled experiment on the provision of choice over lighting conditions and preferences for lighting that providing people with a choice over the lighting – what they labeled as decisional control [2] – had a negative effect on performance in a creativity task. A questionnaire study on indoor comfort in more than 600 Danish homes revealed that a majority of people prefer manual control of the residential indoor environment [7]. For electric lighting, 68% of the respondents preferred manual control, only 3% automatic control, and 20% a combination of automatic and manual control (9% did not know). A similar result was found for solar shading with 58% preferring manual control, 8% automatic control, and 12% a combination of the two. Please note that this survey was done in a residential indoor environment and not in a working environment. Lee and Brand [12] 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 conclude that having personal control over the physical working environment positively influences both job satisfaction and group cohesiveness.

1.3. Daylight and blinds

People generally have a clear preference for daylight over electric lighting as a source of illumination [4]. Studies have shown this preference for daylight also in offices for various reasons, including enhanced psychological comfort, increased productivity, more pleasant office appearance, and assumed health benefits [9,22]. But there is still only little evidence that daylight indeed enhances work performance, as there are many other factors that potentially influence job satisfaction and performance [4]. Nevertheless, Christoffersen and Johnsen [5] found that employees prefer to sit near windows. The most positive aspects of a window according to this study in 20 Danish buildings are to have a view out, to be able to check the weather outside, and to have the ability to open the window. Leather et al. [11] investigated the impact of illumination, sunlight penetration, and view through a window in an office setting on job satisfaction, general well-being, and intention to quit the job. Interestingly, not the level of illumination was important, but rather the size of the sunlight patches in the room and the proportion of natural elements in the available view. The area of sunlight penetration was directly and positively related to job satisfaction and general well-being, and negatively related to intention to quit the job.

Windows can also be a source of visual and thermal discomfort and therefore they come with various forms of blinds to control the amount of daylight that enters through the window. Glare is known to be a primary factor driving blinds usage [15,20]. Several studies investigated the use of manual blinds and show that people do not regularly change the blinds positions [6,10,16]. 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, to save energy, or to create a view [8]. Interestingly, however, Reinhart and Voss [17] found that in 88% of the cases when the blinds were lowered automatically, people manually raised them within 15 min.

Reinhart and Voss [17] investigated the use of an automated blind system with manual override (but no option to switch off the automated behavior) in six 1-person and four 2-person offices at the south–south–west façade of a building in Germany. The offices did not have active air-conditioning and used daylight dimming to provide a minimum of 400 lux on the work plane. The threshold for lowering or retracting the blinds automatically was set at 28 klux (vertical illuminance measured at the façade). The participants were informed about the fact that their blinds usage was monitored. The study ran from end of March to early December. The authors found that people are more likely to accept automatic retracting than automatic lowering of blinds. Lowering of the blinds was only accepted if incident solar gains were as high as 50 klux on the façade ($\pm$450 W/m^2) or if direct sunlight above 50 W/m^2 hit the work plane. Furthermore, they registered on average 3.6 blind