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User satisfaction and interaction with automated dynamic facades: A pilot study

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ABSTRACT

Automatically-operated dynamic facades can play an important role in reducing building energy consumption while maintaining high levels of indoor environmental quality. Facade automation, however, has a controversial reputation due to concerns about increased risks for occupant distraction and discomfort. This paper explores and quantifies the influence of automated facade operation on user satisfaction and interaction by presenting the results of a pilot study. In the experiment with 26 participants, multiple scenarios with varying control strategies and occupant influence options were tested, with a focus on dynamic daylight aspects and visual performance. Analysis of subject responses and data collected during experimental sessions did not directly reveal a high risk for disturbance and discomfort. We found that less frequent but discrete transitions in facade configuration are significantly better appreciated than smooth transitions at a higher frequency. Our findings also emphasize the need for further development of effective facade control algorithms and demonstrate that the ability for manual override is a requisite for high-performance operation of dynamic facades.

1. Introduction

Buildings with dynamic facade components can be adjusted in response to prevailing or anticipated weather conditions and comfort preferences. Doing this adaptation in an effective way, by taking advantage of the available energy sources and sinks in the ambient environment, can lead to a significant energy -saving potential compared to static design alternatives [1,2]. Dynamic facade technology can, in addition, play an important role in balancing various aspects of indoor environmental quality (IEQ), such as, discomfort glare, view to outside, privacy, thermal comfort and air quality [3–5]. Climate adaptive building shells (CABS) are therefore increasingly regarded as a promising concept for achieving high-performance building design [6], and many different adaptable facade design concepts have been proposed [7].

The way of operating CABS has a profound effect on the resulting performance in terms of occupants' comfort and energy savings. Consequently, it is an important factor to take into account in the product development of next-generation CABS concepts and their control systems. It is argued that highest performance gains can be reached when operation of the dynamic facade is appropriately integrated with occupancy detection and the control of other systems, for e.g. lighting, ventilation, heating and cooling [8]. In turn, this is best achieved when facade operation is fully automated, and coordinated by a supervisory building automation system [9].

User interaction and satisfaction are two primary factors that cannot be neglected in the development and operation of automated building systems [10–12]. Several studies in various settings have shown that the levels of perceived and exercised personal control over one's environment are important determinants of comfort, well-being and task performance [13–15]. Recent research in this field has mostly been focused on control of HVAC systems, and considers IEQ mainly in terms of thermal comfort and indoor air quality. Results from the European HOPE project nevertheless show that "satisfaction with the control of sun shading" was one of the main predictors for comfort in relation to personal control [16].

Despite its importance being acknowledged in literature, so far, only limited attention has been paid to human factors research in relation to daylighting, solar control, and the dynamics of adaptable facades [11].

Bordass et al. (1993) make the overall recommendation that "those advocating fully-automatic control of natural light and glare should proceed with caution" [17], and moreover argue that designers and modelers have "over-optimistic faith in automatic

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controls" [18]. In post-occupancy evaluations (POE), they identified, for example, cases of occupant frustration and hostility because automated blinds were often perceived to operate at the wrong time. In a study dedicated to automated facades, Stevens (2001) found a strong positive correlation between occupant satisfaction and their ability to overrule operation of the systems, and moreover found that in such cases a fast-responding control system is required for high performance [19]. These results are supported by studies dealing with venetian blinds [20–22], where also the risk for too frequent oscillations and noisy operation are identified as important factors for occupant satisfaction [20,23]. On a related note, Reinhart and Voss (2003) investigated occupants' tolerance towards automated blind readjustments, and found this to be "remarkably low" [24].

The type of findings presented above, contribute to the controversial reputation of automated facade systems, which may be one of the reasons why the energy-saving potential of such systems is still largely unused in practice. On the other hand, there is also research that seems to justify the growing interest in intelligent facade control systems. POE research conducted by LBNL, for example, shows that provided the systems are carefully designed, commissioned, and maintained, it is possible to develop energy-saving automated control strategies at high occupant satisfaction [25]. The preference for automated systems over manual control was furthermore also found in observational studies with automated venetian blinds [20] and electrochromic windows [26,27].

Considering this overview of literature, it is clear that there are currently no standard guidelines available to support the design of high-performance automated facade systems. Also, from the perspective of control, there are still many research questions regarding the interaction between dynamic facade components and occupant satisfaction. For example, it is currently unknown what type of adaptive control (e.g. slow vs. fast movements, or many small vs. fewer large movements) leads to higher occupant satisfaction. This lack of knowledge may inhibit the product development of next-generation CABS concepts.

In this paper, we present the results of experimental research that was designed to address several of the points raised above. More specifically, the validity of the following hypotheses was tested:

H1 Moving facade elements are a direct cause for disturbance and discomfort.

H2 Frequent but smooth facade transitions are perceived as less disturbing compared to less frequent, but more discrete transitions over a larger distance.

H3 Users with the ability for manual override assess automated movement of facade elements as less disturbing compared to users without override option.

H4 Movement of facade elements is perceived as less disturbing when it relates to a clear cause instead of movement without apparent reason.

2. Methodology

2.1. Test environment

Experiments were conducted in a full-scale test room (5.4 × 5.4 × 2.7 m) (Fig. 1), designed as daylight laboratory at Eindhoven University of Technology, The Netherlands. The west wall of the room is fully glazed and on the interior side equipped with a prototype automated dynamic facade in the form of non-transparent movable roller shades. The position of shades is coordinated by a central control unit and actuated by Somfy Sonesse 30 DCT motors, operated at the lowest speed setting to ensure that the sound induced by the system is hardly noticeable in the center of the room. The upper and lower roller shades are operated independently and can cover a range from fully open to fully closed.

The test subject was sitting behind a desk, at 1.5 m from the facade (Fig. 2). The direction of the chair and table relative to the facade was fixed (Fig. 2), but within these constraints, users were free to adjust the layout of their workspace. Occupants had an unobstructed view to outside, which consisted of a mostly natural setting on a university campus with a pond, trees, and lawns nearby, and other buildings in the distance. The room was only occupied by the test subject. All experiments were carried out in the months April and May. Sensors were installed to monitor daylight conditions in the room and on the work plane (horizontal and vertical illuminance). Additionally, the position of the roller shades was recorded over time.

In some of the tested scenarios, users had the ability to override the automatically determined position of the roller shades. These override actions were controlled using a hand-held user interface (Fig. 3). Users had the option to move both the upper and lower roller shade, and in this way could make the transparent window area bigger, smaller or change its position in the facade.

2.2. Test subjects

In total, 26 test subjects (10 male, 16 female) participated in the experiments. The population of participants had an average age of

Fig. 1. Overview of the experimental facility with roller shades fully opened (left). Small pictures (right) show different facade configurations.