Occupant satisfaction with two blind control strategies: slats closed and slats in cut-off position

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Abstract

Modern highly glazed buildings require solar shading in order to obtain visual and thermal comfort for the occupants in addition to obtain a low energy use of the building. For the system to respond to the external conditions in an intelligent manner, automated operation is needed. When utilising an automatic solar shading system, it is important to use a control strategy that is accepted and preferred by the occupants. Consequently, the objective of this study is to investigate occupant satisfaction with respect to visual comfort under two blind strategies: one simple control strategy with closed slats when the solar shading is activated and one more detailed control strategy that utilises the cut-off angle of the slats or a minimum slat angle of 15˚ when solar shading is activated. Results from the study are helpful in the development of control strategies for blinds and are indications of how blinds should be treated in building design. Responses from 40 participants in a repeated measure design survey revealed that the detailed control strategy was significantly more popular among the test subjects than the simple control strategy. Comments by the participants gave strong indications that view to the outside influenced the choice of preferred control strategy. Even if the detailed control strategy was found to be the most preferred, the results indicate that it was not sufficient to avoid glare. Based on the results, both glare and view aspects should be incorporated in the building design to a greater extent than what is common practice today. It can further be recommended that more effort is put into finding optimal set points for activation of the solar shading and for controlling the tilt angle of the blind in order to obtain a more robust control strategy with limited overrule actions.

Key words: Occupant satisfaction, solar shading, daylight, glare

1 Introduction

Modern commercial buildings are often designed with highly glazed facades. These facades require solar shading in order to avoid or reduce cooling demand, overheating and glare problems and, in some circumstances, in order to provide privacy for the occupants. Blinds are popular shading devices used in office spaces around the world. Blinds provide the flexibility of preventing direct solar radiation from entering the room and, at the same time, give access to diffuse daylight as well as a certain amount of view to the outside if desired. However, the energy reduction potential, as well as daylight and view access, strongly depend on the underlying solar shading control strategy (Grynning et al., 2014; Herkel et al.; Kuhn, 2006) and for the system to respond to the external conditions in an intelligent manner, automated operation is needed (Bunning and Crawford, 2012; Zhang and Birru, 2012).

In building design, it is common practise to model blinds in a simplified way (Kuhn, 2006; Saelens et al., 2014) frequently with a constant g-value which often corresponds to closed slats (Kuhn, 2006). Conducting building simulations with closed slats might lead to advantageous results with respect to solar and glare protection compared to more sophisticated control strategies based on profile angle of sun and cut-off angle of slats (Herkel et al.; Kuhn, 2006). Consequently, Kuhn stress the importance of taking realistic user accepted solar shading control strategies into account in building design in order to ensure planning safety and reliability of a design. Since research has reported that people in indoor spaces generally like to have access to a window for daylight provision and outside view (e.g. (Bodart and Deneyer, 2005; Christoffersen et al., 1999; Collins, 1976)) it might be a moot point if occupants would be satisfied with a solar shading strategy that both obstructs daylight from entering the room and completely blocks the view to the exterior.

Based on a comprehensive literature review, Galasiu and Veitch (2006) found that limited amount of research has focused on occupants' acceptance, preference or satisfaction with automatic solar shading systems. Yet, as intelligent dynamic facades are gaining popularity (Liu et al., 2014; Winther et al., 2010), this knowledge is essential in order to be able to design comfortable buildings for the future. A recent Dutch study (Bakker et al., 2014) found a clear link between automated facade operation and a high risk of disturbance and discomfort. According to Bakker et al. (2014), it might be hard to assess if the occupants understand the reason for the activation of solar shading and thereby appreciate this action. This problem has been seen in other studies as well (Bordass et al., 1994; Inoue et al., 1988) where the occupants thought that the solar shading operated at the wrong times. In a monitoring study, Reinhart and Voss (2003) observed that the users corrected 45 % of 3,005 automated blind adjustments which also indicate that the occupants were dissatisfied with the automatic operation. As Bakker et al. (2014) point out, when the solar shading is activated to prevent one type of discomfort, the comfort on other aspects might sometimes be reduced. Therefore, they emphasise that the balance between preventing glare and providing daylight to the room and view to the outside should be an important issue in any solar shading control strategy. Several simulation studies have used venetian blinds with a cut-off strategy of the slats to achieve such balance (Chan and Tzempelikos, 2013; Gomes et al., 2014; Wienold et al., 2011; Zhang and Birru, 2012). However, Chan and Tzempelikos (2013) and Wienold et al. (2011) have reported that the cut-off strategy might be insufficient to avoid glare. Chan and Tzempelikos (2013) illustrate that fixed tilt angles of 60˚ or higher provide satisfying results for most cases. However, with this recommendation the view aspect is neglected as such tilt angles in practice totally obstruct the view to the exterior.

The objective of this study is to investigate the occupant satisfaction with respect to visual comfort with two blind strategies: (1) a simple control strategy where the slats are closed when the solar shading is activated providing high solar and glare protection, simulating the simplified way blinds commonly are treated within building design, and (2) a more detailed control strategy that utilises the cut-off angle of the slats or a minimum tilt angle of 15˚ when solar shading is activated with the aim of obtaining a balance between preventing glare, providing daylight supply and view to the exterior. Results from the study might aid in the development of control strategies for blinds and give indications of how blinds should be treated in building design. The study will be carried out with use of right-now occupant surveys combined with physical measurements. The study is restricted to focus on the indoor environment close to the occupants' position, which in the present case is close to a window in a cell office like experimental room. The tests will be conducted in the Cube, a test facility at Aalborg University, Denmark.

2 Method

2.1 Facility

The Cube (latitude 57.02°N, longitude 10.0°E) is a test facility at Aalborg University. It has a south-oriented experimental room which is 2.76 m wide, 3.6 m deep and 2.70 m high. Figure 1 gives an illustration of the layout of the Cube and the experimental room. The south wall is equipped with a double layer glazing (2.76 m × 1.60 m) with a U-value of 1.2 W/m²K, g-value of 0.36, direct solar transmission of 0.31 and a visible light transmission at normal incidence of 0.65. The window is equipped with both an internal and external white 65 mm convex venetian blind. The blind systems use a motor connected to a Chassi controller to control the slats according to desired angles.

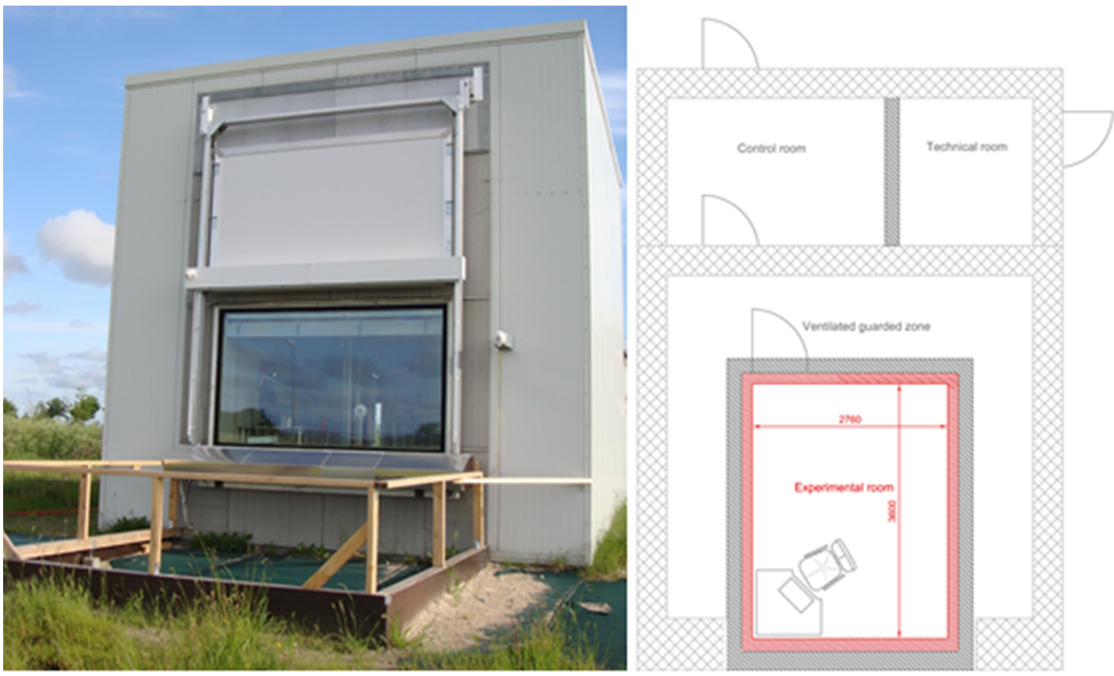


Figure 1: Photo of the facade of the Cube and a top view of the plan layout of the Cube and the experimental room.

The internal surfaces in the experimental room are kept in light colours. The reflectivity of the internal surfaces has been determined using a spectrometer (250 to 2500 nm). Table 1 summarises the visible reflectance of the internal surfaces and their colour.

Table 1: Reflectance and colour of the internal surfaces of the experimental room in the Cube.

Surface	Reflectance	Colour
Walls	0.73	White
Floor	0.32	Grey
Ceiling	0.94	White

2.2 Measurements

2.2.1 Indoor environment

Indoor horizontal illuminance at the work plane was monitored with six illuminance sensors in the centre line of the room, 0.85 m above the floor. Additionally, one illuminance sensor was placed horizontally at the work desk; see the location of the sensors in Figure 2. A illuminance sensor was placed vertically on a wood stand at a height 1.2 m close to the test subject in order to measure the vertical illuminance at the eye level, and one illuminance sensor was placed vertically on the east wall behind the work station at a height 1.2 m, see Figure 2. All sensors were cosine corrected of type Hagner SD1/SD2 detectors connected to a Hagner MCA-1600 Multi-Channel Amplifier. The illuminances were recorded every 10 ms and averaged over one minute.

Operative temperature was measured with grey globe thermometers (d≈40mm), air temperature was measured with silver-coated type K thermocouples protected by a mechanically ventilated silver-shield, and air velocity was measured with hot-sphere anemometers. These measurements were carried out for three, five and four positions in the room respectively at four heights for each position (0.1 m, 0.6 m, 1.1 m and 1.7 m) confirming to recommended measurement height for a seated and standing person according to ISO 7726 (1998), see Figure 2.

2.2.2 Weather data

Vertical irradiance was measured on the facade before and after the glazing by use of CMP21 and CMP22 pyranometers. Two additional pyranometers were placed horizontally on the top of the roof of the experimental room in order to record the global radiation and the fraction of diffuse solar radiation.

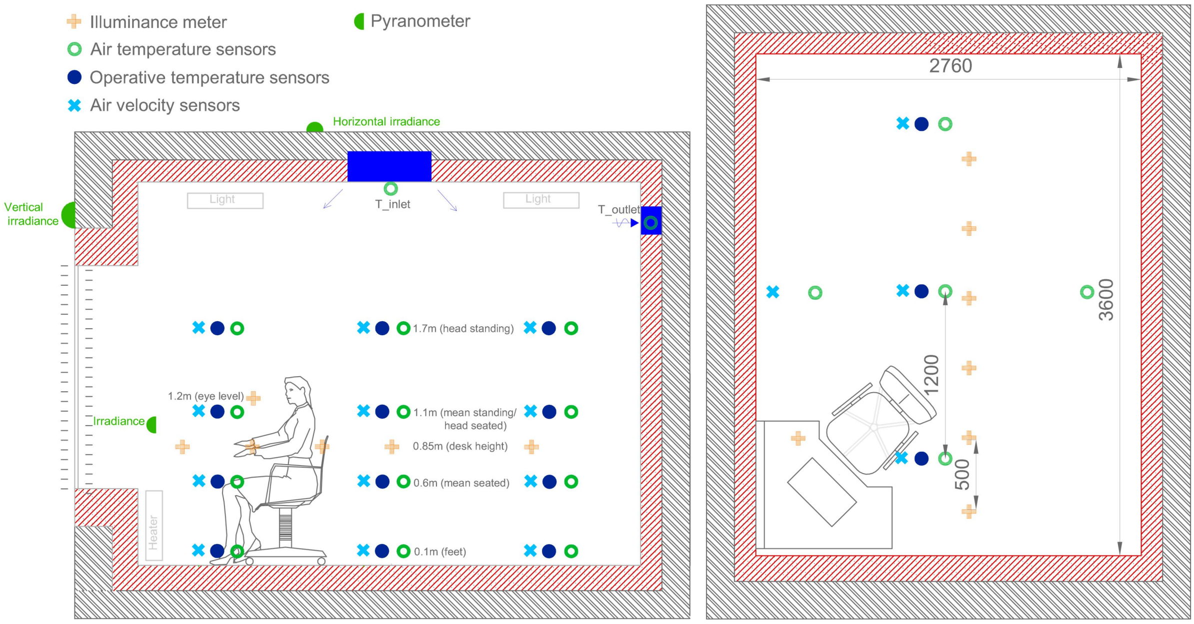


Figure 2: Placement of sensors in the experimental room.

2.3 Procedure

2.3.1 Participants

Forty-six subjects took part in the study, taking place in May–June 2014. Responses from 40 of the test subjects were usable for the comparison of the two solar shading strategies; the subjects counted 22 males and 18 females. The participants were mainly university students, researchers or office workers in the age range 20-62 years old (mean 28.7 years, median 26 years, SD 8.3). The subjects were instructed to wear vision corrected lenses or glasses if these were normally worn in office work situations.

2.3.2 Introduction to the test and test facility

Prior to the test, the subjects were informed that they should participate in a test to evaluate the visual and thermal environment in the experimental room in the Cube under two different solar shading strategies. In order to reduce biases caused by the test persons having or not having experience with the test room from previous visits, the test subjects conducted a pre-test up to 10 days before the main test. In the pre-test, the subjects were thoroughly introduced to the test and the experimental room, they got familiar with the concepts of glare and thermal comfort and the scales they would use in the test to rate the glare sensation and thermal comfort. Additionally, they answered some personal questions regarding gender, age and occupation. In total, the pre-test lasted for approximately 20-30 minutes.

During both the pre-test and the main test, the subjects were facing diagonally towards the window (45˚), which is assessed as a worst case situation with respect to daylight glare probability in an office work situation. A line of sight directly towards the window will of course cause higher probability of glare; however, this viewing direction is assessed as less common in an office environment. The subjects had the opportunity to adjust the height of the office chair, but they were instructed not to adjust the computer screen in order to secure the same pre-set viewing direction for all test subjects.

2.3.3 Control of indoor environment

The main test was a repeated measures design where all the subjects were exposed to both blind strategies illustrated in Figure 4. In the detailed control strategy, vertical illuminance at eye level was used as an indication of glare and applied as criteria for activation of the solar shading. Tzempelikos and Shen (2013) have recommended using transmitted illuminance rather than external solar radiation as control parameter in terms of visual comfort and lighting considerations since it normalize the threshold for a particular space independent of glazing properties. The set-point of 2000 lux was selected based on the simplified linear correlation between vertical eye illuminance and persons disturbed by glare developed by Wienold and Christoffersen (2006), expressed as the simplified daylight glare probability (DGPs) given in equation 1.

$$DGP_s = 6.22 \cdot 10^{-5} \cdot E_v + 0.184 \qquad (1)$$

In activated state of the detailed control strategy, the slats are tilted according to the estimated cut-off angle, i.e. the angle where direct solar radiation is prevented while maximum view contact to the exterior is provided. However, the minimum tilt angle of the slats was set to 15˚ in order to avoid negative cut-off angles in situations with large solar altitude angles and thereby avoid view to the sky and high risk of glare (Bülow-Hübe, 2007). The cut-off angle was calculated according to equation 2 (O'Neill et al., 2007). Where d is the profile angle of the sun, s is the spacing between the slats, w is the width of the slats, α is the solar altitude angle and γ is the solar surface azimuth, see Figure 3. When activated, the whole window is shaded by the blind and all the slats have the same angle position.

$$\beta_{cut-off} = \sin^{-1}(\cos(d) \cdot s/w) - d \qquad (2)$$

$$d = \tan^{-1}[\tan\alpha / \cos(\gamma)] \qquad (3)$$

Figure 3 shows the cut-off angle as a function of the profile angle for the venetian blind system used in the present study.

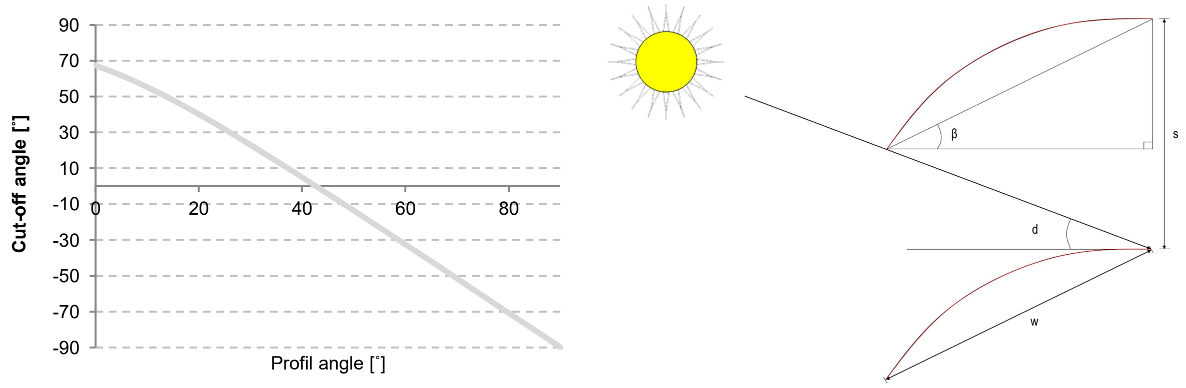
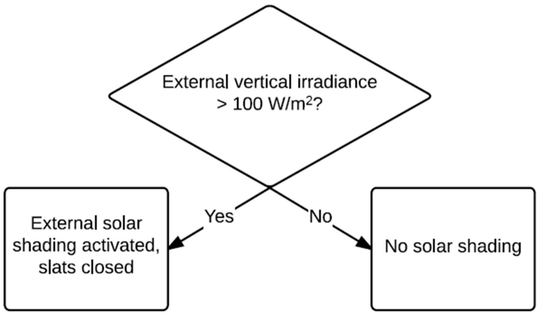


Figure 3: Left: Cut-off angle as function of profile angle for a venetian blind system with 65 mm wide slats and 60 mm spacing between the slats. Right: Illustration of the parameters included in equation 2 and 3 for determination of the cut-off angle.

When a test subject entered the experimental room, one of the control strategies was activated. Yet, the solar shading was only activated if needed, according to the criteria given in the two solar shading strategies. Only responses from test subjects exposed to both control strategies are used in the analysis in comparing the two solar shading strategies (*n*=40).

The temperature set points for heating and cooling were 21˚C and 24.5 ˚C respectively for all the tests. If daylight alone could supply minimum 300 lux at the horizontal work plane 1.5 m into the room, no artificial lighting was added. If not, general artificial lighting from the ceiling was added to maintain an illuminance of 500 lux at the work plane.

Simple solar shading control strategy:



Detailed solar shading control strategy:

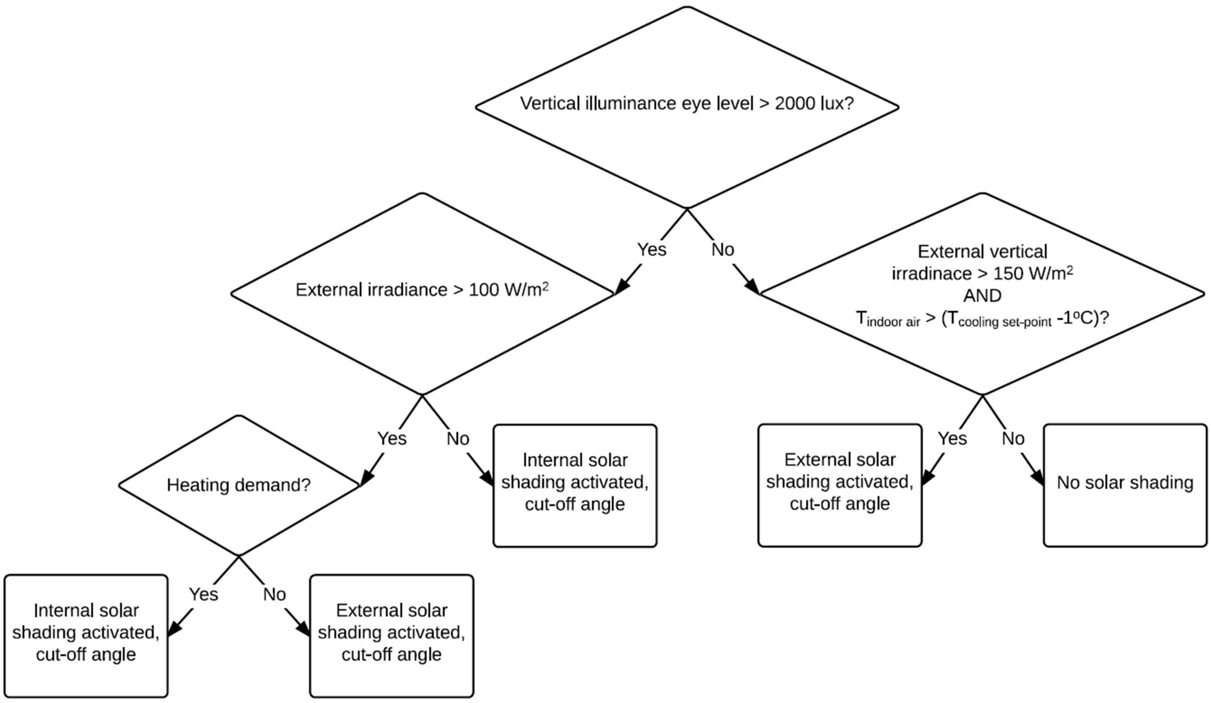


Figure 4: Schematic illustration of the simple and detailed control strategy.

2.3.4 Questionnaire and test procedure

Test subjects were asked for their subjective feedback by completing a web-based questionnaire constructed in Surve Xact (Rambøll, 2014). The questionnaire was made with categorical scales with verbal labelling. Five or fewer points were used for unipolar scales, and seven or fewer points were used for bipolar scales. According to Nicol (2008), it is generally agreed that accuracy is not significantly improved by adding more than seven points to the scale. A mixture of odd and even point scales was used.

In order to evaluate the visual comfort and glare, the basic questions and surveying procedure given in Christoffersen and Wienold (2005) were adopted. This procedure entails that the occupants perform different visual tasks like reading from a paper, reading on a computer screen and writing on a computer while their performance is recorded. In this way, the occupants will perceive the visual environment in a similar manner as in a normal working situation. This procedure is in line with recommendations given in the international project IEA SHC task 21 (Velds et al., 2001).

Conducting the assigned tasks and answering the questionnaire took approximately one hour for each solar shading control strategy, see Figure 5. Between exposures to the two control strategies, the test subjects were able to take a break lasting 5-10 minutes. The same questionnaire was completed for both control strategies. However, the assigned tasks were slightly changed by exchanging the texts to read and re-type. After completing the two tests, the participants were asked which control strategy they preferred, with the options “First control strategy”, “Second control strategy” and “No preferences”. They were also given the opportunity to provide supplementary comments regarding their choice. The order of exposure to the different solar shading strategies was randomised and balanced between the test subjects and time of day.

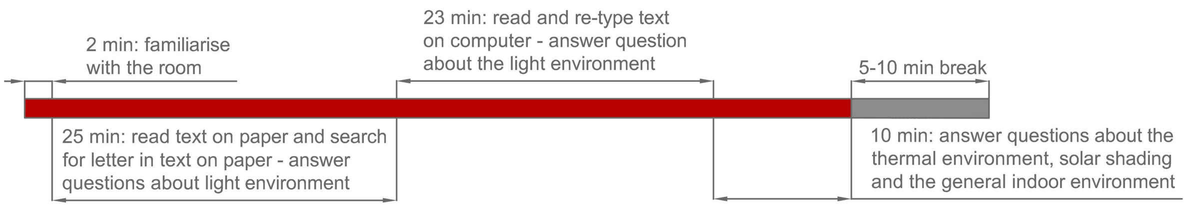


Figure 5: Time schedule for the conducting the test. The test is repeated twice, one time for each control strategy.

2.3.5 Data analysis

The occupants’ responses of the visual and thermal environment were combined with physical measurements. Measurements of horizontal and vertical illuminance used in the data analysis were averaged over the 15-20 last minutes before the occupants answered questions regarding the light environment and perception of glare, while measurements of the temperatures were averaged over the 30 last minutes before questions regarding the thermal environment were answered.

Statistical analyses were carried out to identify significant differences between levels of independent variables or to identify dependencies between variables. In comparison of indoor environmental conditions and participants’ responses between the two control strategies, a paired t-test was used. In using the paired t-test procedure, we assume that each observation pair is statistically independent of the other pairs; this is commonly satisfied by a randomised test procedure as used in this survey. Additionally, we assume that the pair-wise differences are approximately normally distributed. Normality has been checked for all comparisons by use of normal probability plots. An unpaired t-test was used for comparison of two groups where pairing was not practical or purposeful. These analyses were carried out analogue to the paired t-test. Where data was considered to be far from normally distributed, it was analysed initially by use of non-parametric statistical tests, e.g. Wilcoxon rank sum test. A shortcoming with non-parametric tests is that they are less powerful for detecting differences than the parametric versions. The significance of association between categorical variables was tested with the Fisher exact test in combination with

Monte Carlo (MC) simulations. Statistical data analysis was performed using R i386 version 3.1.1 (Gentleman et al., 2014).

3 Results and discussion

Within the temperature ranges occurring in the test room, the occupants did not report significant differences in perceived thermal comfort between the two control strategies. It is therefore presumed that the small differences occurring in the thermal environment did not affect the test subjects' perceived visual comfort. In this section, the analyses and outcomes from the experiments will therefore be presented in relation to the occupants' satisfaction with the visual environment under the two solar shading control strategies and their preferences towards the solar shading. Figure 6 gives an example of how both the luminance conditions and the horizontal illuminance levels across the test room at 0.85 m above the floor might vary throughout a sunny day for each of the control strategies. The figure clearly shows that both the access to daylight and view to the exterior are better for the detailed than for the simple control strategy.

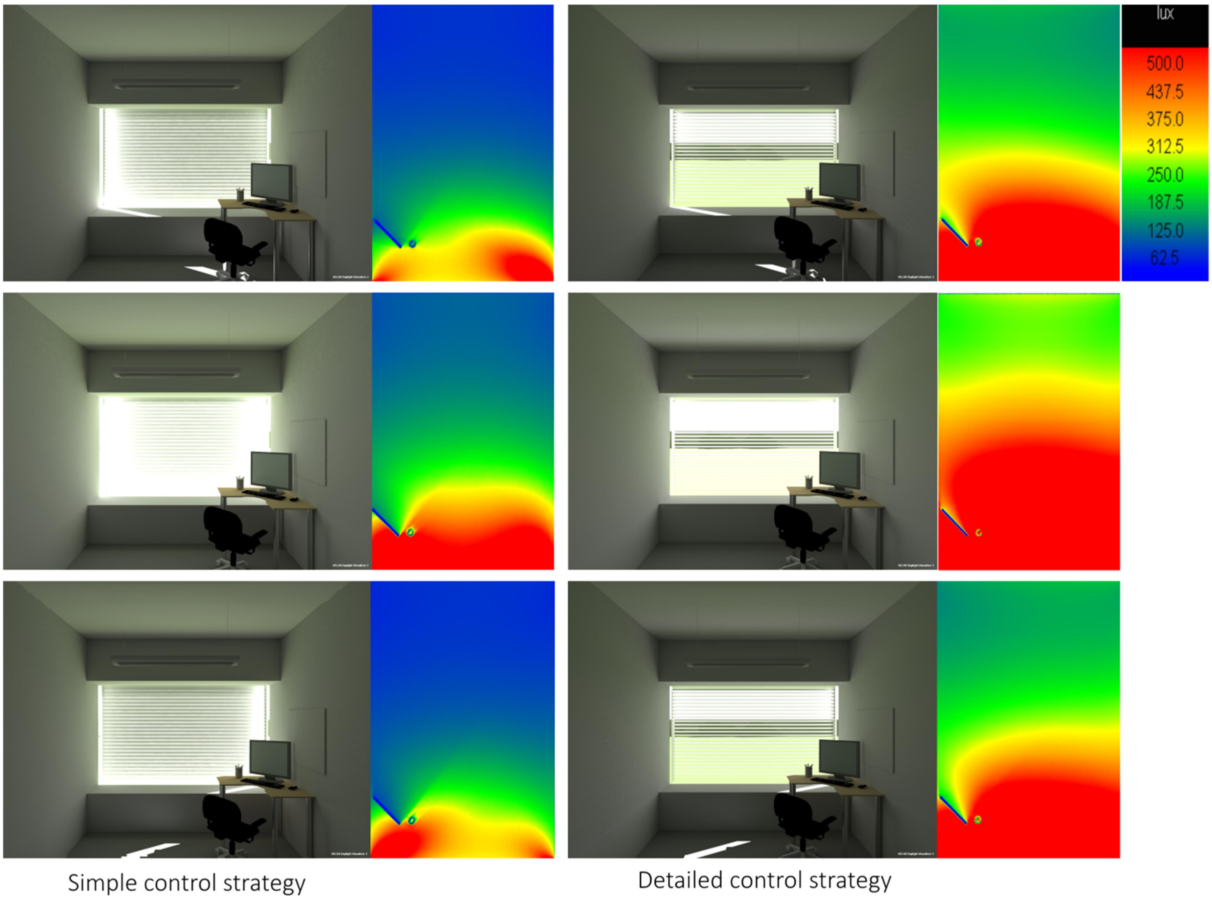


Figure 6: Rendering of the luminance (perspective) and illuminance (horizontal plane 0.85m above floor) in the test room for the two solar shading control strategies. The horizontal illuminance values are represented with a false colour scale where red indicates values equal or above 500 lux (for interpretation of the references to color, the reader is referred to the web version of this article). The rendering is done by use of Velux Daylight Visualizer (LUXION) for sunny sky conditions on May 21th at 09.00 AM (upper row), 12.00 AM(middle row) and 03.00 PM (lower row).

3.1 Illuminance when reading on paper

Figure 7 (a and c) shows a box-plot of the mean horizontal illuminance at the desk and the mean vertical illuminance at eye level recorded during the paper task for the simple and the detailed control strategy. As expected, there is a prominent difference in the illuminance between the control strategies and the detailed control strategy provides more daylight to the room. A paired t-test suggests that the measured horizontal illuminance at the desk is significantly higher during the detailed control strategy than during the simple control strategy (p= 1.1e-13). Figure 7 (b and d) summaries the participants' responses with respect to satisfaction with the light level for reading a paper under each of the strategies and their rating of the light level. The plots indicate that a higher number of people are dissatisfied with the light environment for doing the paper task during the simple control strategy than during the detailed control strategy, primarily since they rate the light level as low. Analysing the data statistically using paired t-tests suggests that the participants rate the light level as higher during the detailed control strategy than the simple control strategy (p=2.6e-3) and that they are significantly more satisfied with the detailed control strategy for reading on paper (p=0.04). Even though the participants generally are more satisfied with the light level for reading a paper under the detailed control strategy, a paired t-test suggests that both glare from window and glare from shading device are reported as higher (p=4.9e-3 and p=0.04) for the detailed control strategy compared to the simple control strategy. Yet, only 1 and 5 participants out of 40 rated the

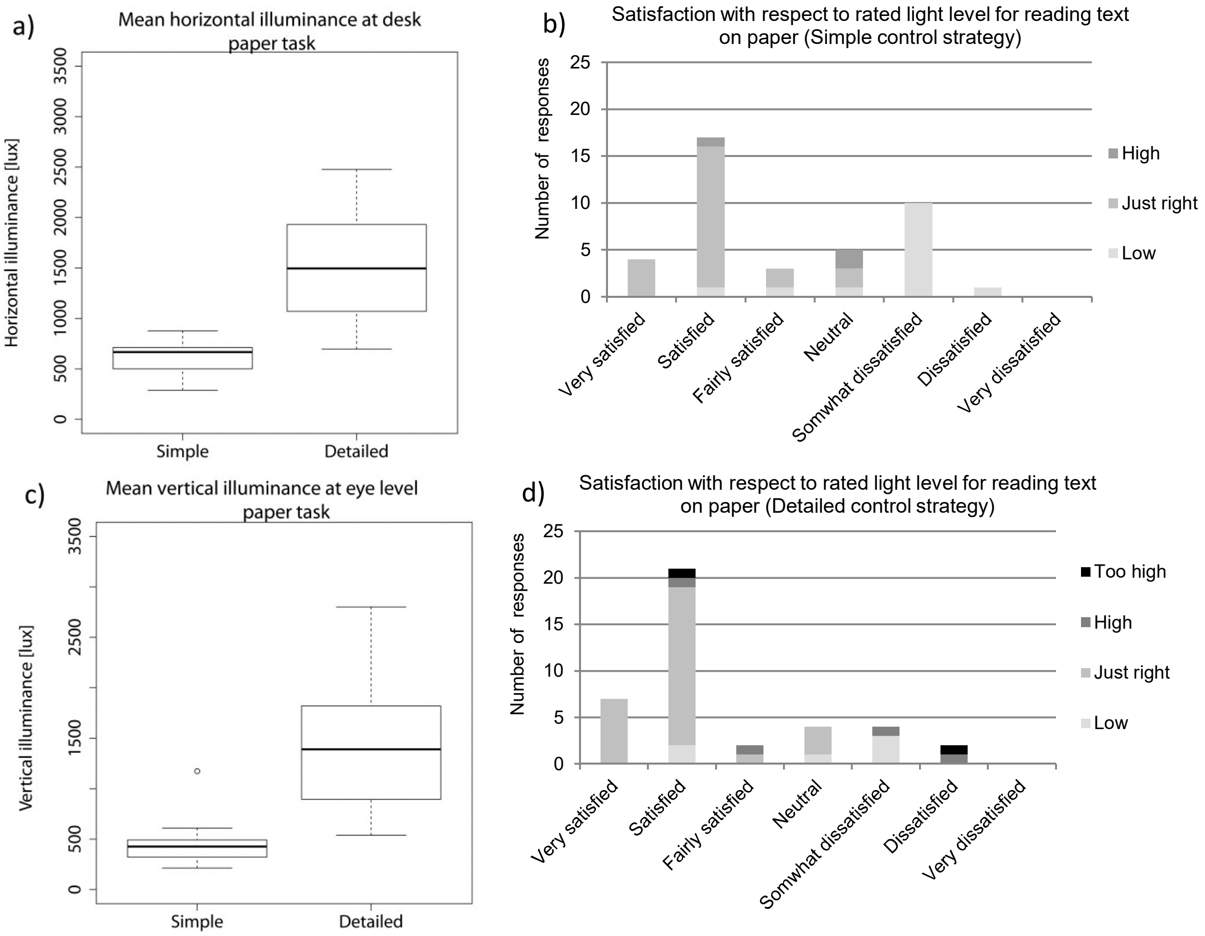


Figure 7: a) box-plot of mean horizontal illuminance at the desk during paper task, b) Response regarding satisfaction with the light level and rated light level during the simple control strategy, c) box-plot of mean vertical illuminance at eye level during paper task, d) Response regarding satisfaction with the light level and rated light level during the detailed control strategy.

glare to be disturbing or intolerable on the four point scale *imperceptible, noticeable, disturbing or intolerable* for the simple and detailed control strategy respectively, which from a glare point of view is still rather acceptable.

3.2 Illuminance when working on computer

Figure 8 (a and c) shows box-plots of the mean horizontal illuminance at the desk and mean vertical illuminance at the eye level during the computer task. Similar to the results from the paper task, both the horizontal and vertical illuminance are significantly higher during the detailed control strategy than during the simple control strategy (paired t-test, p=1.3e-12 horizontal and p = 2.8e-13 vertical) and the participants rate the light level during the computer task to be significant higher for the detailed control strategy (paired t-test, p= 0.02). A significantly higher level of glare from both window, shading device and reflections from the computer screen is also reported for the detailed control strategy according to a paired t-test (p= 1.3e-05, p=0.03 and p=0.02 respectively). Now there is an increase in participants rating the glare to be disturbing or intolerable during the simple and detailed control strategy, 10 and 13 participants out of 40 respectively.

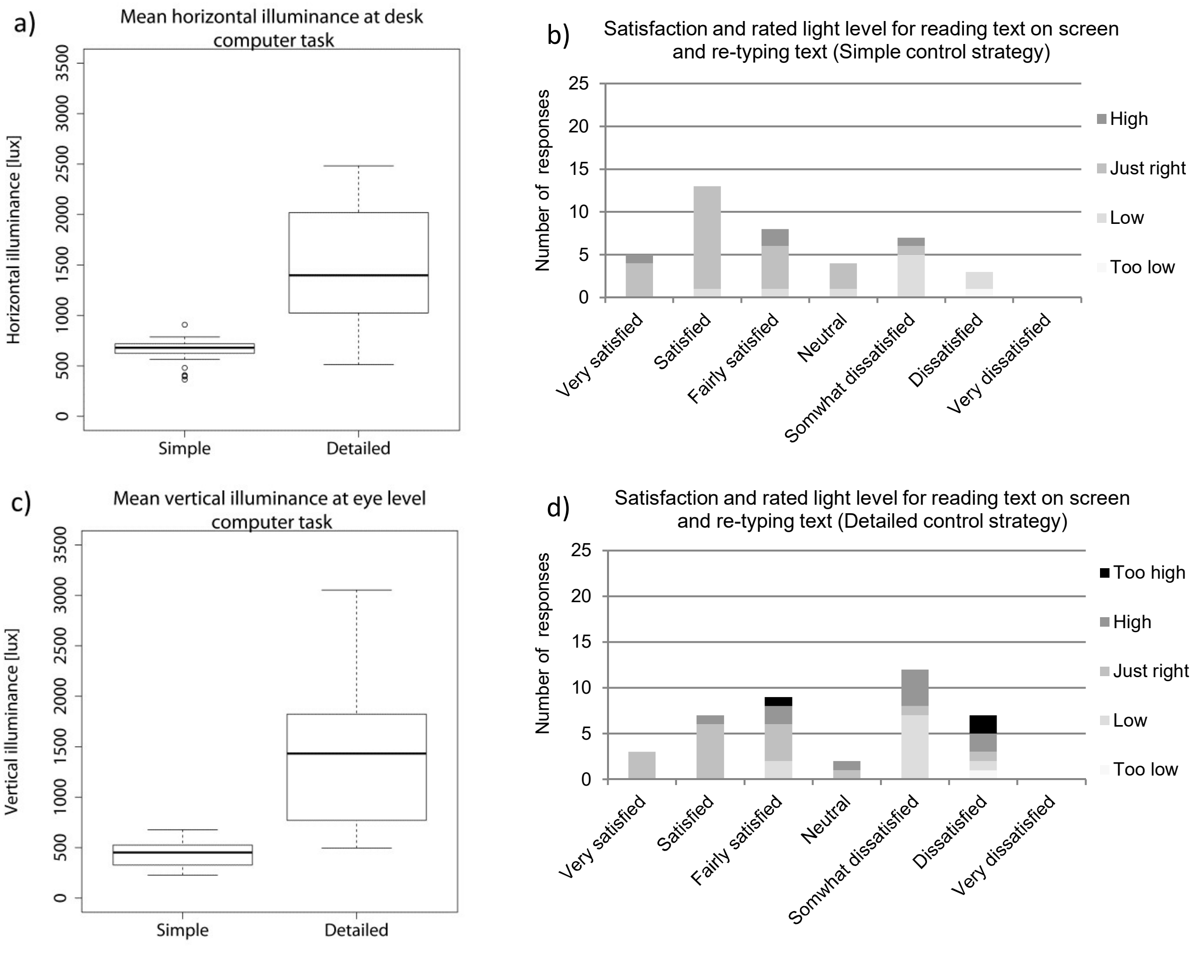


Figure 8: a) box-plot of mean horizontal illuminance during computer task, b) Response regarding satisfaction with the light level and rated light level during the simple control strategy, c) box-plot of mean vertical illuminance during computer task, d) Response regarding satisfaction with the light level and rated light level during the detailed control strategy.

When looking at the box-plots for vertical illuminance during paper task and computer task (Figure 7c and Figure 8c), the illuminance level during each strategy seems rather similar and no statistically significant differences are detected for either of the control strategies (paired t-test, p= 0.45 simple and p=0.89 detailed). However, a paired t-test suggests that the glare is rated as significantly higher during the computer task than during the paper task for both the simple and the detailed control strategy (p=0.03 and p=3.6e-03 respectively). This supports the statement that discomfort glare from windows is a more considerable concern when working on a computer since the line of sight is more horizontal than for reading and handwriting tasks on the desk (Bülow-Hübe, 2008; Osterhaus, 2005). This might be a contributing reason as to why, in contrast to the response during the paper task, the participants now seem to be more satisfied under the simple control strategy than the detailed control strategy, and this is supported by the results from a paired t-test (p=5.3e-3).

3.3 Solar shading

A concern regarding use of automatically controlled solar shading systems is the acceptance by occupants. User interaction and occupant satisfaction are two important factors in development and operation of automated solar shading systems. Robust control strategies should have the occupants' acceptance and limit the number of overrule actions. When the test subjects were asked if they felt that the blinds needed to be changed to maintain a comfortable work place, surprisingly similar responses were given during the two control strategies and a considerable part of the participants require change, see Figure 9. The Fisher exact test does not indicate any dependency between control strategy and reported preference to change the blinds (p=0.86). However, the reason for wanting to change the blinds, cf. Figure 10 (a and b), significantly depends on the control strategy (Fisher exact test, p=0.04). As anticipated, the dominant reasons for wanting to change the blinds during the simple control are particularly to provide better view to the outside as well as wanting more light into the room and to the desk, which confirms that daylight supply and view to the exterior is important factors for occupants' satisfaction. Additionally, a number of people would like to let more solar gain into the room. Reasons for wanting to change the blinds during the detailed control strategy are more mixed. There are still some test subjects wanting more light into the room and better view to the outside, but now noticeable more changes would regard the request for less glare as well, which is in accordance with earlier reported glare ratings.

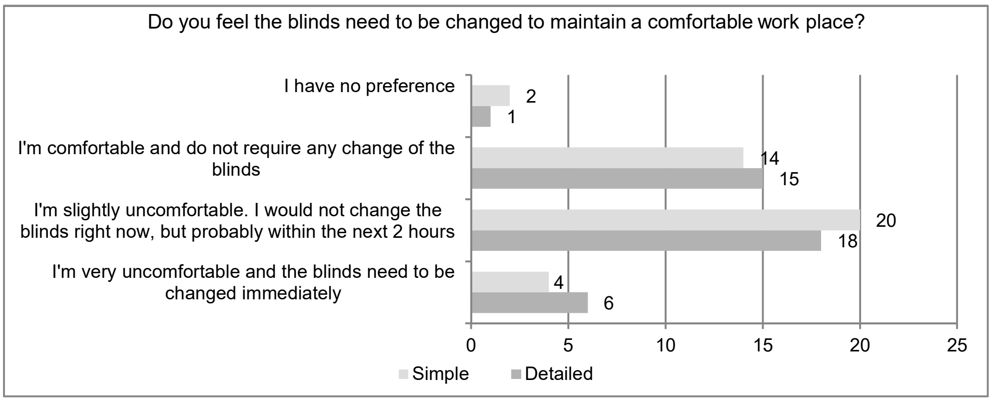


Figure 9: Reported preference for change of blinds for the simple and detailed control strategy in order to maintain a comfortable work place.

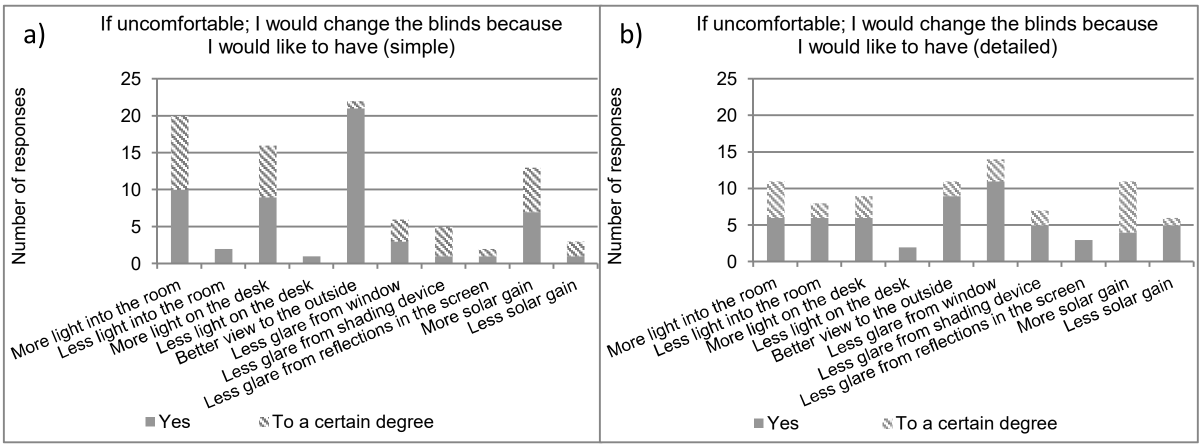


Figure 10: Reported reasons for changing the blinds during the simple control strategy (a) and the detailed control strategy (b). The participants could check as many explainary factors for wanting to change the blinds as desired.

Several studies have reported that having personal control over the physical workspace leads to higher satisfaction with the indoor environment and increased occupant comfort (Bakker et al., 2014; Lee and Brand, 2005). The importance of personal control is supported by the responses in this study, see Figure 11.

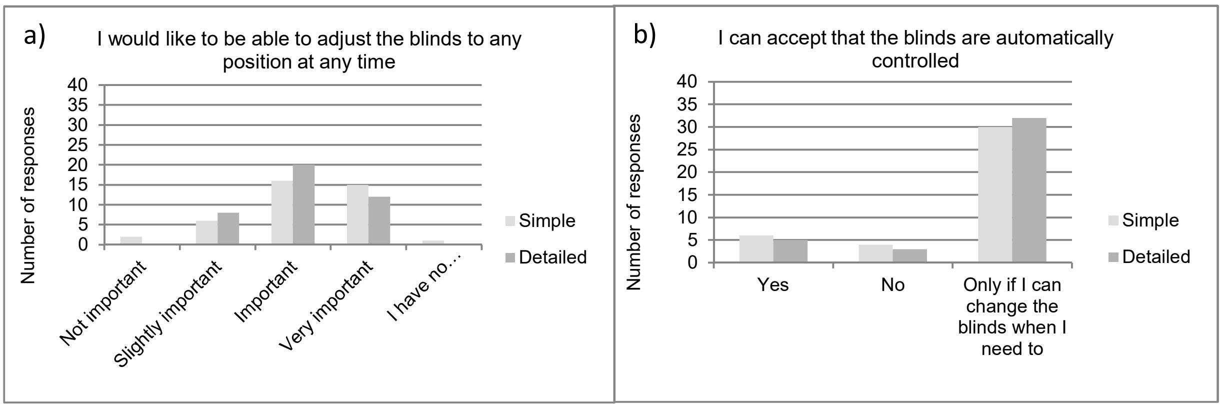


Figure 11: Preferences for personal control of the solar shading and oppertunity to overrule the automatic control.

4 Preferred solar shading control strategy

After completing the test under each control strategy, the test subjects were asked about which control strategy they would prefer in their daily office work. They could choose among one of the control strategies with which they had been presented or select “No preference” if they liked both of the control strategies or neither of them. With respect to experience from indoor environment surveys, it is next to impossible to obtain an indoor environment where everybody is satisfied (EN ISO, 2005; Wienold and Christoffersen, 2006). Therefore, it would be expected that a few test subjects are not satisfied with the simple or the detailed control. This assumption is confirmed by the responses from the test subjects; see Figure 12a where three participants have selected the option “No preference” and where their supplementary comments are interpreted as them not liking either of the control strategies. However, what is more interesting in this case is to assess if the detailed control strategy is significantly more popular than the simple control strategy. An exact binomial test suggests that there is a significantly higher probability that the detailed control strategy is preferred rather than the simple control strategy (n=37, p=0.02).

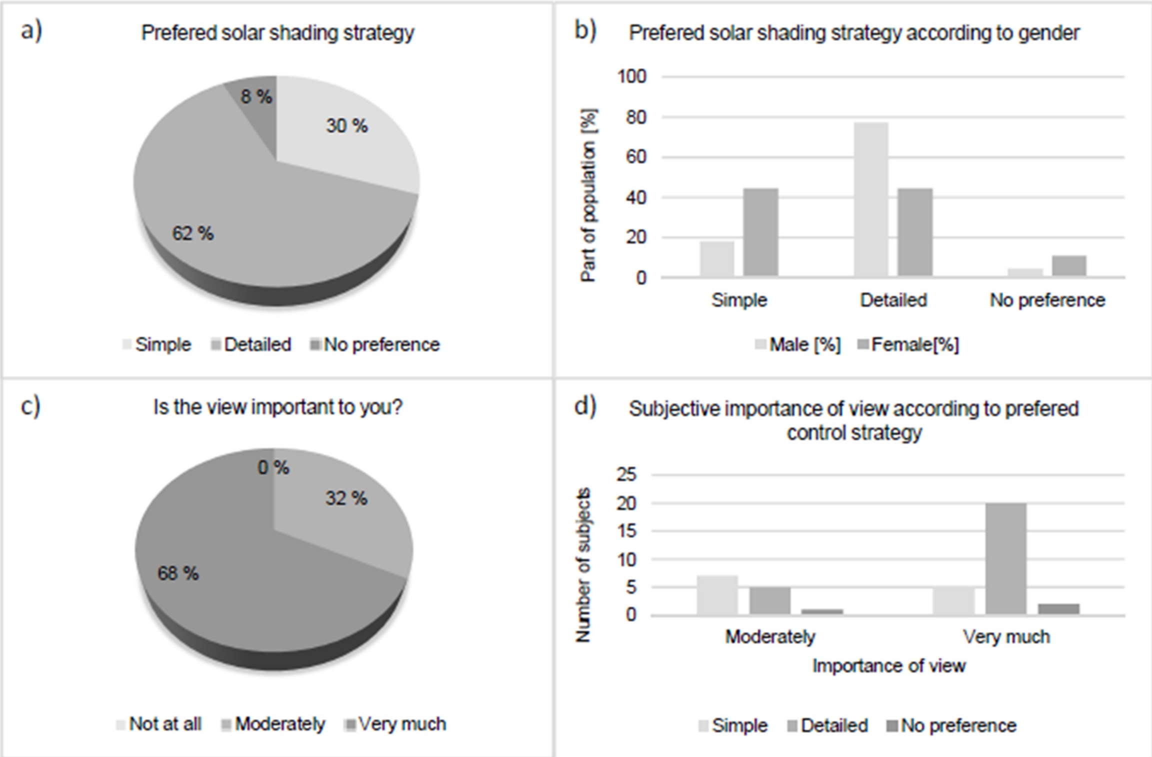


Figure 12: a) Reported preferred solar shading control strategy. b) Illustration of preferred control strategy with respect to gender. c) Reported subjective importance of view. d) Illustration of subjective importance of view with respect to preferred solar shading control strategy.

Further, it is of interest to inspect if there are some variables which might contribute to predict the choice of control strategy. Figure 12b visualizes the percentage of males and females who selected one of the two control strategies or the option "No preference". Using a Fisher test the analysis suggests that there is no significant dependence between the gender and preferred control strategy (MC= 2e+07 replicates, p=0.08).

Another variable of interest is the test subjects' subjective rating of importance of view. Earlier research has reported that occupants may extend his or her tolerance level towards discomfort glare if pleasant view were present (Chauvel et al., 1982; Hopkinson, 1972; Osterhaus, 2005; Tuaycharoen and Tregenza, 2007). In this study it is seen that the participants report higher disturbance by glare during the detailed control strategy than the simple control strategy, the detailed control strategy is nevertheless more preferred. This might be correlated to the phenomenon that the participants might tolerate some disturbance due to glare as long as they have access to view to the outside. Supplementary comments regarding preferred solar shading strategy also gives strong indications that view to the outside influences the choice; this is also consistent with the response reported in Figure 10 which illustrated that the participants particularly wanted to change the blind during the simple control strategy to obtain better view to the exterior. Figure 12c illustrates that all test subjects rated view to be either moderately or very important, and Figure 12d illustrates the rated importance of view with respect to their preferred control strategy. The majority of the subjects rating the view as very important prefer the detailed control strategy. However, a Fisher exact test suggests that the dependence between choice of preferred control strategy and rated importance of view is just outside the range of being categorized as statistically significant (MC= 1e+08 replicates, p=0.06).

Due to differences in the outdoor weather conditions and time of day when the different tests were completed, there are some variations in the indoor conditions which the test subjects were exposed to during the two control strategies. When assessing the box-plots for horizontal and vertical illuminance, Figure 7-Figure 8, the variations are severe under the detailed control strategy while the conditions seems to be much more uniform for all test subjects under the simple control strategy. So, it is interesting to explore if there are any prominent differences in the indoor environmental conditions between test subjects preferring the simple and the detailed control strategy (n=37) during the detailed control strategy.

Figure 13 (a and c) gives box-plots for the horizontal and vertical illuminance with respect to the preferred control strategy for the paper task and computer task during the detailed control strategy. According to a t-test, the horizontal and vertical illuminance conditions are significantly higher during the detailed control strategy for those test subjects preferring the simple control strategy than for those preferring the detailed control strategy (p=2.6e-04 and p=0.01). Figure 13 (b and d) illustrates the response of satisfaction with the light environment during the paper task and during the computer task. An Exact Wilcoxon rank sum test suggests that the test subjects preferring the detailed control strategy report a significantly higher satisfaction with the light environment both for the paper task and the computer task during the detailed control strategy than those preferring the simple control strategy (p=0.03 and p=3.0e-03).

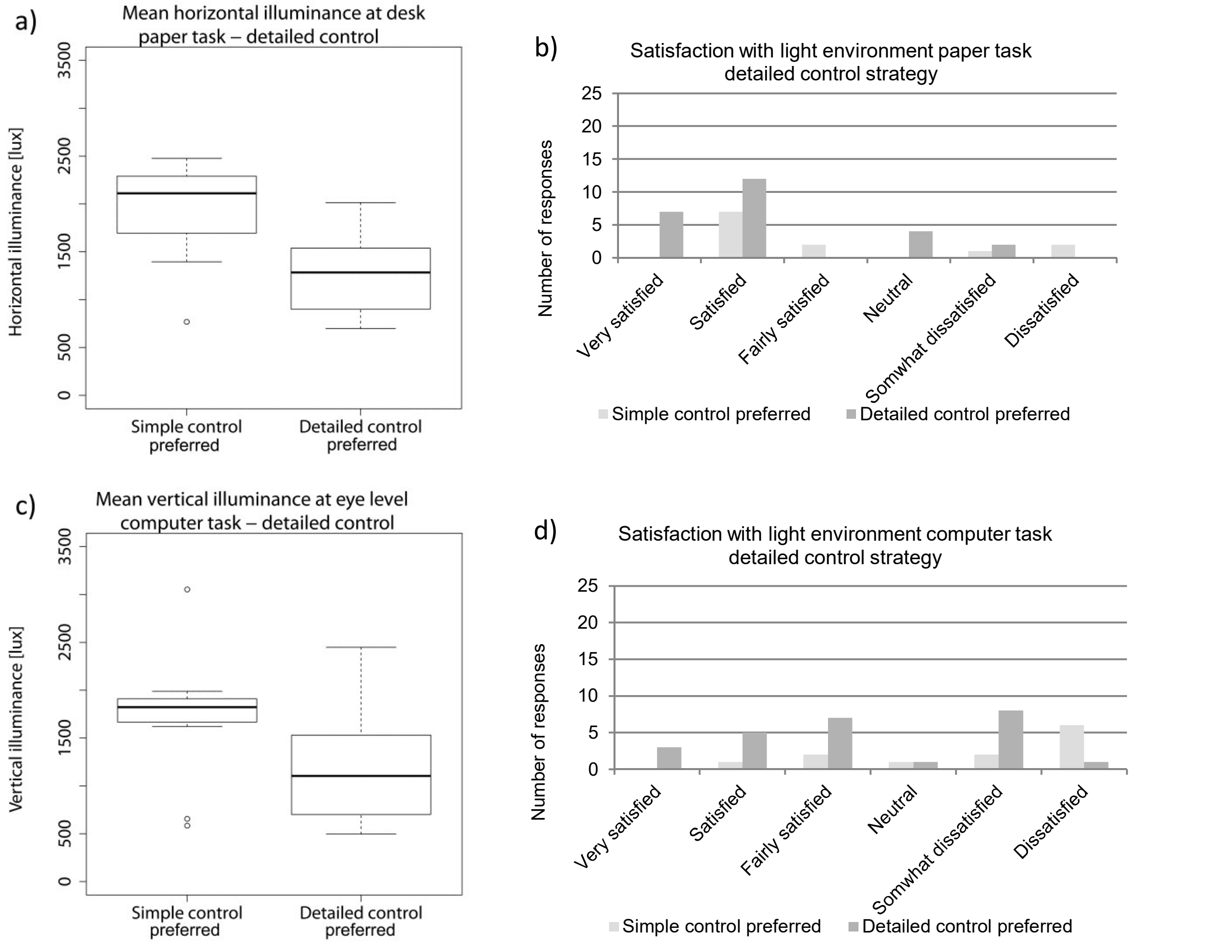


Figure 13: a) Box-plot of the mean horizontal illuinance when doing paper work during the detailed control strategy. b) Satisfaction with light environment when doing paper task during detailed control strategy. c) Box-plot of the mean vertical illuinance when doing computer work during the detailed control strategy. d) Satisfaction with light environment when doing computer work during detailed control strategy.

These last comparisons and findings indicate that there might be space for improvement of the detailed control strategy in order to obtain higher acceptance by the occupants. The box-plots for vertical illuminance (see Figure 7c, Figure 8c and Figure 13c) reveal that illuminance levels above the set point of 2000 lux occur at several occasions even if the solar shading was activated. However, when the solar shading is activated and slats tilted to its cut-off angel or minimum 15˚, no further adjustments are made with the current control strategy. One improvement might be to make the control tilt the slats to an angle larger than the cut-off angle or 15˚ if the set point for vertical illuminance is still exceeded after activation (Chan and Tzempelikos, 2013; Wienold et al., 2011). For practical implementations, careful consideration of the frequency of the movement must be considered for such strategy. Based on the box-plot for vertical illuminances during computer work (see Figure 13c), another improvement in the detailed control strategy might be to lower the set point of the vertical illuminance. With this correction, there might be a possibility that some of the subjects who now prefer the simple control strategy would be more satisfied with the detailed control strategy as well.

5 Conclusion and recommendations

This study was carried out with the objective of investigating the occupant satisfaction with respect to visual comfort under two blind strategies: one simple control strategy simulating how blinds commonly are simplified within building design where the slats are closed when the solar shading is activated and one more detailed control strategy that utilise a cut-off angle or minimum 15 ˚ of the slats when solar shading is activated. Responses from 40 participants in a repeated measure design survey revealed that the detailed control strategy was significantly more popular among the test subjects than the simple control strategy.

Comments by the participants strongly suggested that view to the outside influenced the choice of preferred control strategy. This is an important aspect which needs attention both in development of solar shading strategies and with respect to treatment of blinds in building design. At the present time, there is no standardized method to assess view; however, proposals have recently been given (Hellinga, 2013; Wienold, 2009). It is recommended that proposed models should be verified and possibly improved in order to take the influence of view on occupant comfort into account in building design.

The results further indicate that a cut-off strategy is not sufficient to avoid glare, even though a lower limit of the slat angle of 15˚ was set for the current case. Insufficiency of cut-off angles to avoid glare has earlier been reported in simulation studies (Chan and Tzempelikos, 2013; Wienold et al., 2011). Since glare seems to be a considerable concern, it is recommended that glare analysis should be incorporated into building design to a greater extent than what is common practice today. This should though be done in combination with daylight supply and view assessment in order to avoid recommending solar shading products or strategies that totally block the view contact to the exterior, since this study indicate that a certain amount of glare might be accepted by the occupants as long as view to the outside is available.

On an overall basis the results implies that the simplified treatment of blinds with a constant g-value corresponding to closed slats commonly used in building design might be insufficient when the aim is to make realistic building performance predictions. Therefore, it is recommended that building designers consider realistic control strategies and apply building simulation tools which incorporate models that take angular properties of solar shading devices into account in a physical acceptable manner.

With respect to development of solar shading strategies, it is recommended that further effort is put into finding optimal set points for activation of the solar shading and for controlling the tilt angle of the blinds in order to obtain a robust control strategy with limited overrule actions.

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