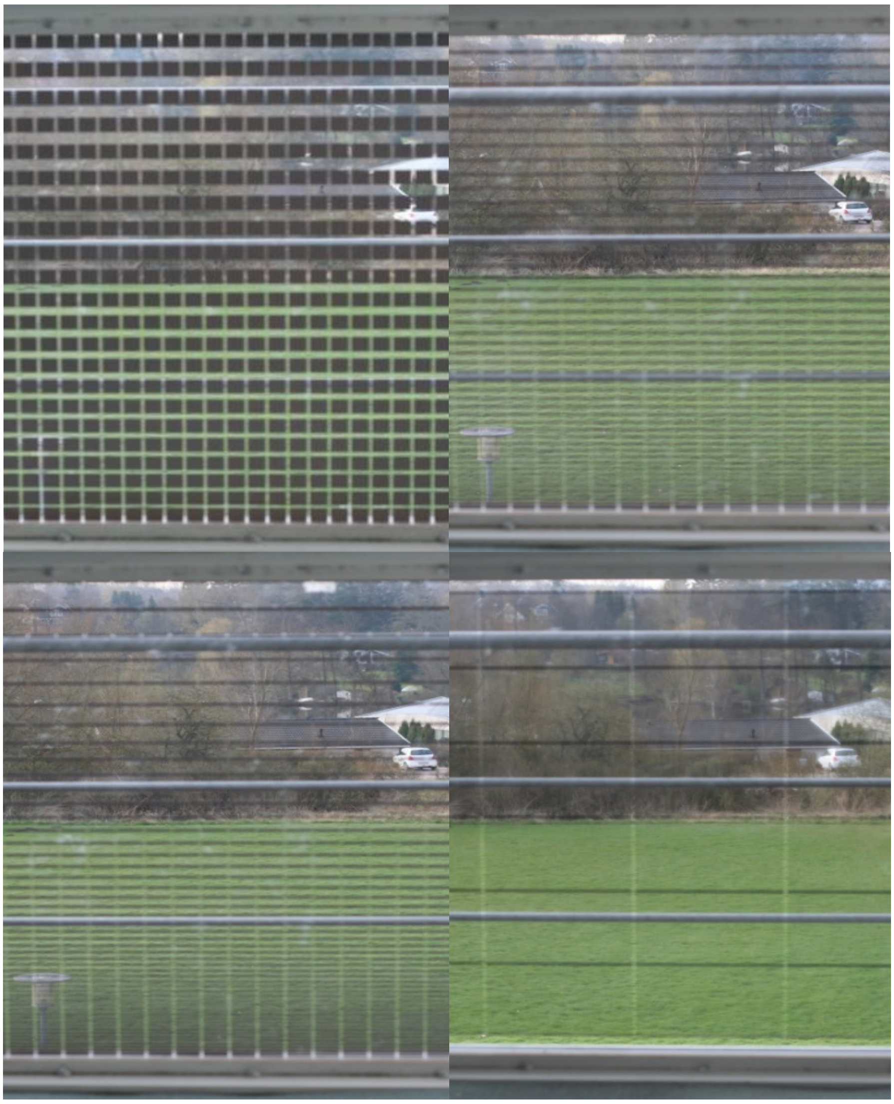
SBi 2012:2x

Assessment of indoor light and visual comfort when applying solar cells in transparent facades



Statens Byggeforskningsinstitut
AALBORG UNIVERSITET

Assessment of indoor light and visual comfort when applying solar cells in transparent facades

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Preface

This project is one step on the way towards making it attractive to integrate semi-transparent PV modules as light-filters in glass facades and finding ways on how to do this. How the PV modules are integrated in the glass facades does influence the users' perception of the daylight in the room and the view to the outside, which is the focus dealt with in this study.

The work is part of the project "Application of thin-film technology in Denmark" (Thi-Fi-Tech) has been supported by **Energinet.dk** under the PSO-ForskEl programme with the ref. no. 2008-1-0030. It has been carried out in the period March 2008 to June 2012. The overall objective of the project is to document and demonstrate the economic, functional and aesthetical potential of thin-film PV installations under typical Northern European conditions.

This report is based on work started by Jens Christoffersen and continued by Steen Traberg-Borup. The project part of which the Danish Building Research institute (SBi) was responsible was finished in corporation between the authors of this report. We want to thank Karin Scheibel for calling in and having the communication with all test persons and helping with various practicalities.

The Thi-Fi-Tech project has been carried out by a team including:
Danish Technological Institute (project leader), Danish Building Research Institute, En2tech, EnergiMidt A/S, PhotoSolar A/S, Gaia Solar A/S, Caspersen & Krogh Arkitekter A/S, Entasis, Esbensen Rådgivende Ingeniører A/S, Arkitema A/S, Danfoss Solar Inverters A/S.

The project is documented in several reports available at the DTI web-site:

http://www.teknologisk.dk/projekter/projekt-thi-fi-tech/32454

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Contents

Summary

This study was a part of the project ”Application of thin-film technology in Denmark” (Thi-Fi-Tech). The aim was to demonstrate how the integrating transparent thin-film PV in glazed facades in building with large glass areas influences the users' perception of the daylight in the room and the view to the outside.

Panels with various patterns were constructed representing façade-integrated thin-film, both for collecting solar energy, to filter the daylight and reduce solar loads in the room. Four different dummy thin-film panels were evaluated at the daylight laboratory facility at the Danish Building Research institute in two different tests and periods, i.e. in each test there were two different panel patterns at the time in two equally arranged test rooms.

After working half a day in a test room office having a large glass area where the upper and lower part was covered with an integrating transparent dummy thin-film panel, the test persons evaluated the daylight in the room and the view to the outside by answering questionnaires. Each of the four panel patterns were evaluated by 19 test persons. Besides the illuminance levels in the test rooms were measured at various strategically places and analysed.

During test 1 the Pattern 4 and 6 were tested against each other as they resemble a similar structure, with the transparency of the pattern increasing towards the window in the middle. The difference between the two patterns is the geometry of the cells and the transparency. Pattern 4 was having opaque cells as lines with a cell dimension of 5.15 mm x 39.10 mm and a transparency of 72 %, whereas Pattern 6 had quadratic cells with a cell dimension of 27.64 mm x 27.55 mm and a transparency of 38 %.

During test 2 the Pattern 3 and MicroShade pattern were tested. Pattern 3 was very similar to pattern 4 with the transparency of the pattern increasing towards the window in the middle and having opaque cells as lines with a cell dimension of 4.96 mm x 39.10 mm and a transparency of 74 %. MicroShade is a special type of solar shading constructed of transparent strips of stainless steel bands with micro-structure perforations being angled so that they shield to direct sunlight, while the clear view is maintained. MicroShade is specified having a shading coefficient by normal radiation of approx. 0.63, and on a summer day approx. 0.25.

During test 1 the test persons preferred the striped pattern 4 opposed to the square pattern 6. MicroShade was evaluated more positive compared to the striped pattern 3 (being very similar to the striped pattern 4 used in the first experiment). The lowest overall average illumination was found in the room with MicroShade. The variation in the light intensity in the room with MicroShade was less than what was found in the room with Pattern 3, in which higher illumination levels were measured. The measured light intensities were corresponding well to the transparency of the panels and test persons perception of the illumination levels. Since higher illumination levels was preferred during test 1 and the lowest illumination levels preferred during test 2, there was no link between the test persons' evaluations being positive and a high illumination level of the room. However, much higher light

intensities were measured during the 2nd test vs. what was measured during the 1st test.

Both the view through the pattern and the appearance of objects outside was evaluated negatively for the room with the square pattern 6 unlike the striped pattern 4.

We found that if structures of the transparent PV panels cannot be very small as for the MicroShade panels, then patterns, where the horizontal line and an undisturbed view to the outside is somehow maintained, seems to be preferred. We conclude that the horizontal striped patterns tested in these tests were preferred over squared patterns. Moreover, MicroShade seems to influence the light environment positively compared to the three other test panels. The view through the MicroShade panels is maintained except from the color perception of objects outside which was evaluated as being changed unlike the other test panel results. In the room with MicroShade the light intensity fluctuations and light intensity differences seemed to be reduced caused by the geometrical micro-structure perforations in the MicroShade panels.

Introduction

The objective of “LIGHT&ENERGY – proof of concept” is to substantiate the architectural potential of light-filtering semi-transparent PV panel in transparent façades, and furthermore to identify a consortium capable of performing a full-scale demonstration of such PV applications in buildings.

The project is a part of a three-step initiative “LIGHT&ENERGY” which seeks to pave the way for full architectural acceptance of semi-transparent PV panels as attractive light filters in glass facades, and furthermore to exemplify how these panels create viable openings for building with large glass areas, also after the prospected restrictions of the Danish building regulations. The entire activity spans the process from the first explorations to full-scale demonstration in buildings.

The applied project “LIGHT&ENERGY – proof of concept” forms the bridge between the conceptual studies in the initial on-going project “LIGHT&ENERGY - exploration” (2006-1-6302) and a future full-scale demonstration of the principle worked, see Figure 1.

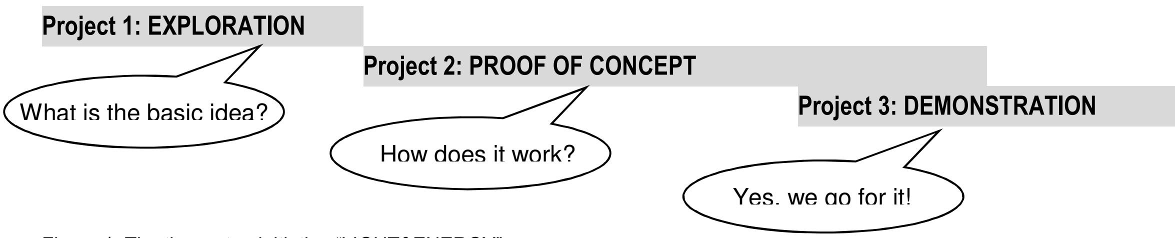


Figure 1. The three-step initiative “LIGHT&ENERGY”.

Aim of experiments

The aim of the experiments is to demonstrate how the integrating transparent thin-film PV in glazed facades in building with large glass areas influences the users’ perception of the daylight in the room and the view to the outside.

Experimental setup, method and materials

Important aspects of integrating transparent thin-film PV in glazed facades is how it influences the users' perception of the space, the daylight in the room and the view to the outside. Therefore a number of PV panels were designed in order to test these aspects.

Description of panels (pattern and transparency)

Panels with various patterns were constructed representing façade-integrated thin-film, both for collecting solar energy, to filter the daylight and reduce solar loads in the room. The dummy thin-film panels have been evaluated at the daylight laboratory facility at the Danish Building Research institute. They were evaluated both with regard to the visual environment by test subjects through questionnaire surveys and with regard to physical measurements of the illuminance levels in the test rooms.

Dummy panels with various patterns

Table 1 below describes the seven different panels available or designed by Caspersen & Krogh Arkitekter A/S. The panels with patterns 1 and 2 were chosen as they resemble 'standard' patterns from some manufacturers. The patterns of panel 3, 4, 6 and 7 were chosen based on the idea that the transparency should increase in the person's view from inside through the window, while the larger density towards the edges would counteract glare from the bright sky (upper panel) and block unwanted insight from below the horizon (lower panel).

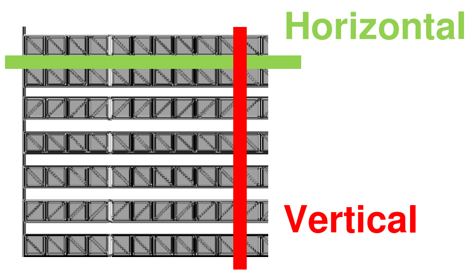
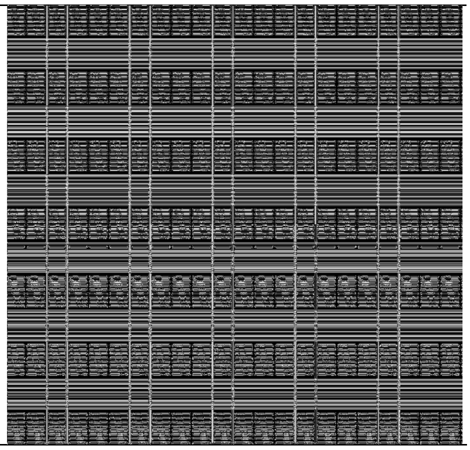
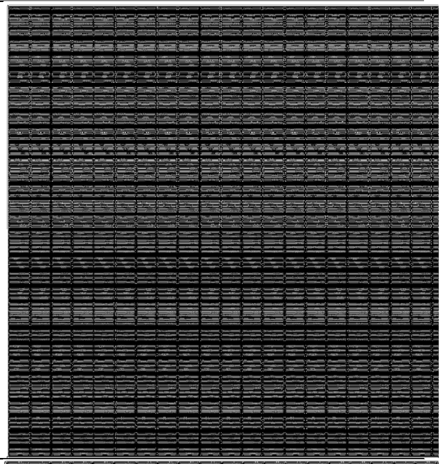
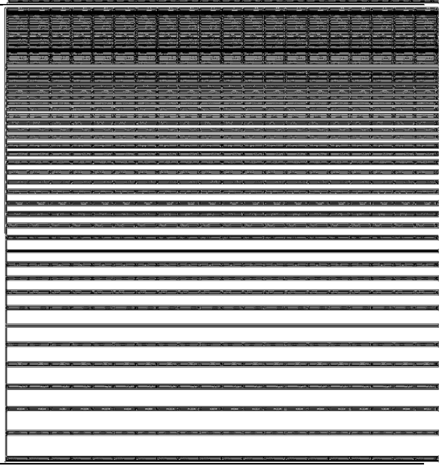
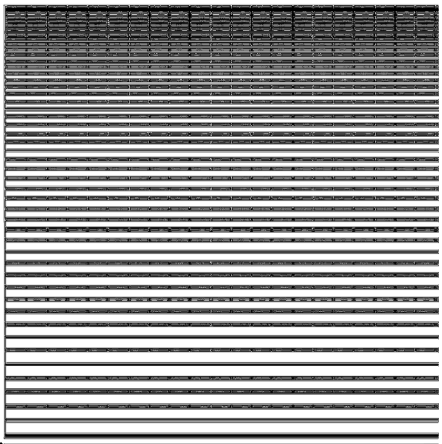
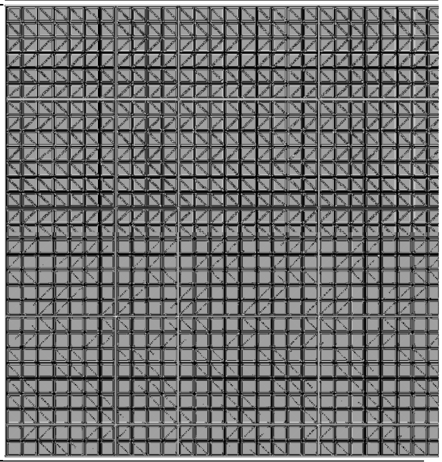
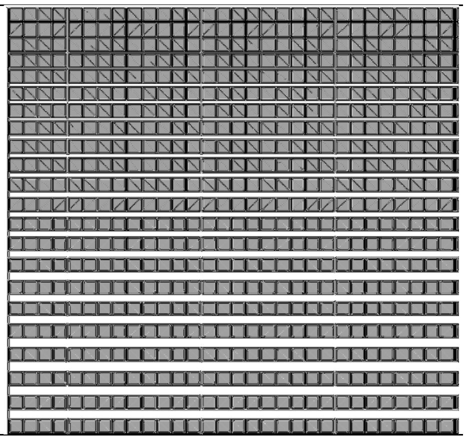
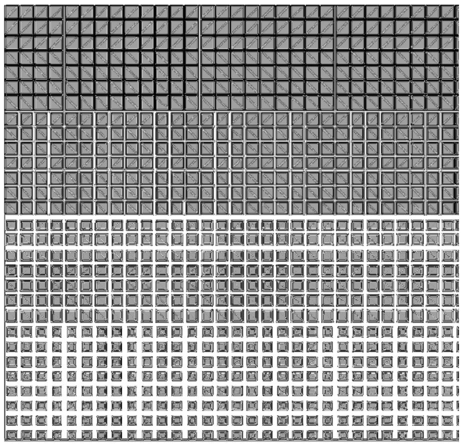


Figure 2. Sketch defining the location of the vertical and horizontal gap in the patterns.

Table 1. Description of the seven different panel patterns. The panels are oriented as being placed in the upper window part. For placement in the lower window part the panels with varying distance between the cells was turned 180 degrees.

1	<u>Distance from edge:</u> 2 mm <u>Vertical:</u> 3.97 mm between the cells <u>Horizontal:</u> 4.00 mm between the cells <u>Cell dimension:</u> 4.03 mm x 37.84 mm <u>Transparency:</u> 54.59%	

2	<u>Distance from edge:</u> 2 mm <u>Vertical:</u> 2.50 mm between the cells <u>Horizontal:</u> 2.50 mm between the cells <u>Cell dimension:</u> 4.97 mm x 39.10 mm <u>Transparency:</u> 37.62%	
3	<u>Distance from edge:</u> 2 mm <u>Vertical:</u> 2.50 mm between the cells <u>Horizontal:</u> Varying distance between cells – from 1.50 mm to 25 mm with increments of 0.50 mm <u>Cell dimension:</u> 4.96 mm x 39.10 mm <u>Transparency:</u> 74.13%	
4	<u>Distance from edge:</u> 2 mm <u>Vertical:</u> 2.50 mm between the cells <u>Horizontal:</u> Varying distance between cells – from 1.00 mm to 45 mm with increments of 0.50 mm to 1.00 mm <u>Cell dimension:</u> 5.15 mm x 39.10 mm <u>Transparency:</u> 72.02%	
5	<u>Distance from edge:</u> 2 mm <u>Vertical:</u> 3.00 mm between the cells <u>Horizontal:</u> 3.00 mm between the cells <u>Cell dimension:</u> 27.63 mm x 27.41 mm <u>Transparency:</u> 18.83%	

6	<u>Distance from edge:</u> 2 mm <u>Vertical:</u> 3.00 mm between the cells <u>Horizontal:</u> Varying distance between cells – from 3.00 mm to 23 mm with increments of 1.00 mm <u>Cell dimension:</u> 27.64 mm x 27.55 mm <u>Transparency:</u> 38.12%	
7	4 vertical bands of cells, with same dimensions each <u>Distance from edge:</u> Varying distance to cells respectively: 2, 4, 6 and 8 mm <u>Vertical:</u> Varying distance between cells: 3, 7, 11 and 15 mm <u>Horizontal:</u> Varying distance between cells: 3, 7, 11 and 15 mm <u>Cell dimension:</u> Varying cell dimensions (B x H): 27.64 x 27.55 mm, 23.64 x 23.55 mm, 19.64 x 19.64 mm, and 15.64 x 14.92 mm <u>Transparency:</u> 49.05%	

MicroShades (PowerShades)

MicroShade is a special type of solar shading constructed of transparent strips of stainless steel bands with micro-structure or micro-fins.

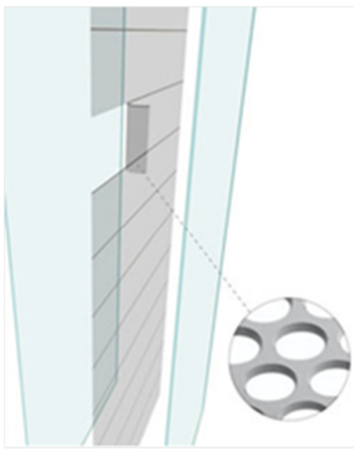


Figure 3. Illustration of the MicroShade stainless steel bands with perforations mounted in a 2-layer glazing

The bands, which are mounted inside of the outer glass in a 2- or 3-layer glazing during production, consist of many small perforations. The perforations are angled so that they shield to direct sunlight, while the clear view is maintained. The shading is selective, both in terms of solar elevation angle and relative to the azimuth angle. While the shading coefficient by normal radiation is approx. 0.63, it is approx. 0.25 on a summer day (used in a 2-layer low-energy glazing).

The system is designed in Denmark, can be found in several types of patterns in the microstructure of the stainless steel strip, which is 70 or 140 mm wide and has a thickness of less than 0.2 mm, will absorb a portion of the solar heat, whereby they will expand more than the glass. Therefore, they are only glued to the glass along one edge, so that they can expand without problems.

Figure 4 shows a microscopy-photography of the structure of micro-fins. The angle of the openings determines the amount of the direct radiation that passes from a given direction. The typical angle is 16 °, but the vanes are also available with an angle of 23 ° for the more shielding and 40 ° for use skylights. The manufacturer (PhotoSolar) is developing a PV-version of MicroShades called PowerShades.

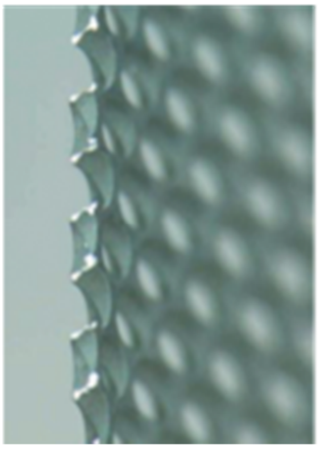


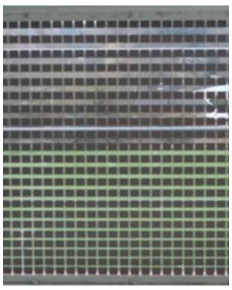
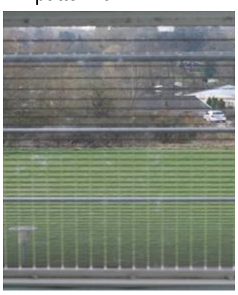
Figure 4. Microscopy- photography of the structure of MicroShade micro-fins.

Patterns applied for the investigations

The PV patterns applied for the investigations are 3, 4, 6 and the MicroShade pattern.

During spring 2010 the patterns 4 and 6 were tested against each other while during spring 2012 pattern 3 and the Microshade (MS) pattern were tested (Table 2).

Table 2. The different test panels being evaluated by tests persons in the daylight laboratory in Hørsholm, Denmark

Test period	Room A	Room B	Comments
Spring 2010 26.4 - 10.5 Test 1	PV pattern 6  ✓ Quadratic cells ✓ Transparency of 38 %	PV pattern 4  ✓ Opaque cells as lines ✓ Transparency of 72 %	Pattern 4 and 6 were tested against each other as they resemble a similar structure, with the transparency of the pattern increasing towards the window in the middle. The difference between the two patterns is the geometry of the cells and the transparency. The difference in cell geometry influences the transparency of the two patterns.
Spring 2012 12.3 - 23.3 Test 2	PV pattern 3  ✓ Opaque cells as lines ✓ Transparency of 74 %	MicroShade (MS)  ✓ Steel bands with micro-structure ✓ Transparency of ? %	The MS has a very open and see through structure. Therefore it was chosen to test the MS against pattern 3 as pattern 3 resembles the most transparent pattern.

The evaluations have been made during two periods of 10 days during spring 2010 (April 26th till May 10th, Test 1) and spring 2012 (March 12th till March 23rd, Test 2).

Description of the Daylight Laboratory

The Daylight Laboratory at the Danish Building Research institute (SBi) is located in Hørsholm, North of Copenhagen (latitude 55.868N, longitude 12.498E). The laboratory has two south-oriented experimental rooms, referred to as room A and room B (see Figure 5 and Figure 6).

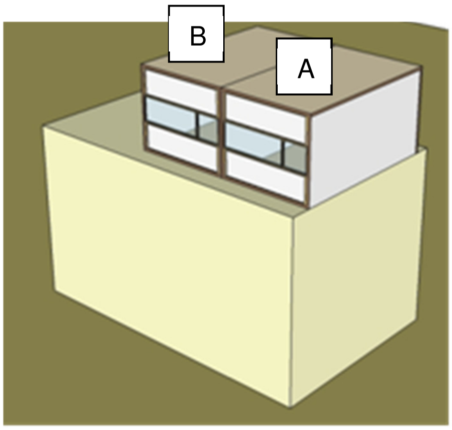


Figure 5. Model of the test facility at SBi with the two identical test rooms facing South. The rooms are named A and B as indicated. The upper and lower part of the glass area in the front façade was partly shielded with selected test panels during tests.

The rooms are orientated 7 degrees east of due south to allow maximum amounts of sunlight to fall on to the glazing, but with minor outside obstructions to the west. The two rooms are characterized by identical photometrical properties (R_{wall} = 0.62, $R_{ceiling}$ = 0.88, R_{floor} = 0.11) and geometrical features (3.5 m wide, 6.0 m deep, 3.0 m high). The rooms have a glass area covering the whole façade and with a light transmission of LT = 72 %, U-value of 1.1 W/m^2 K and a total solar energy transmission of TST = 59 % (g-value). The glass area in the middle of the façade was not shielded but in the upper and lower part of the façade the daylight access to the room was reduced by panels with different patterns as described above partly shielding the glazing area, see Table 2.

Light sensors and test-room interior

Sensors for measuring the illuminance were placed strategically and discrete in the rooms not to distract the test persons unnecessarily, see Figure 6.

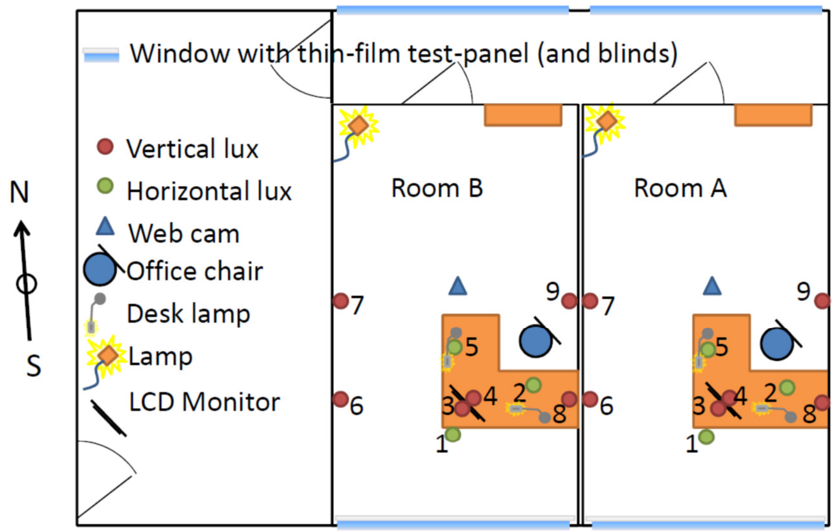


Figure 6. The two test-rooms showing the position of sensors and furniture during the experiments.

In each room, three sensors were measuring horizontal illuminance on the work desk and behind the desk towards the window, 85 cm above floor level (sensor 1, 2 and 5). Four sensors (sensor 6-9) were placed vertically on the walls 1.2 m above floor level at distance 1.2 m and 2,4 m from the window. Two sensors were placed on the LCD monitor measuring the vertical light coming towards the test-person from behind the monitor (against light, sensor 3) and light coming from the back of the room as seen from the LCD monitor (background light, sensor 4). During the experiments, readings of the illuminance level at the sensor locations were made with 30 seconds intervals.

A web cam was placed in the middle of each room taking pictures of the façade each 30 minutes to document the position of the blinds, which the test persons could control freely, to avoid glare.

One lamp was placed behind the door to the right hand side when entering the room whereas a bookcase was placed against the northern wall to the left hand side. These objects were to make the room more nice and relaxed.

Measurements – illumination

The measured illumination in the rooms during the experiments for various sensor combinations was analysed both regarding vertical and horizontal illumination.

Mean values were calculated for the morning session between 9:45 and 11:45 HR and the afternoon session between 13:00 and 15:30 HR. Moreover average values per experimental day (average of morning and afternoon session) for each of the two different rooms were found.

Indirect vertical illumination on the sidewalls was found as being the mean value of sensor 8 and 9 during the morning hours and the mean value of sensor 6 and 7 during the afternoon hours. This sensor selection during the morning and afternoon respectively secured that no sensors with direct sunlight through the window was included in the mean.

Horizontal illumination on the work desk was the mean of sensor 2 and 5 during the same time intervals. As a measure of the light coming towards the test person from the façade (against light) sensor 3 was used whereas sensor 4 was used describing the light received from the room as background light being measured at the LCD monitor position.

Statistics – illumination

The various averages of illumination per period (P), i.e. morning and afternoon illumination of various sensor combinations, were analysed with the test-panel-treatment (T) and period (P) as the explanatory variables for the two different tests separately (spring 2010 and spring 2012, respectively) and combined. The test subjects (person) were included as random effects. In addition, the same analysis but without the explanatory variable P was executed. The mixed model procedure (PROC MIXED) of SAS was used for the computation (SAS Institute, Cary, NC).

The four test-panels included in the dataset (two panels from each of the two tests) and various analyses described above were compared by least square mean tests.

Questionnaire survey

Each test day, the subjects were asked to be in the daylight laboratory from 9:30 to 16:00 HR. They were asked to perform office working tasks, i.e. working on their own computer or reading at the desk. During the morning one test subject were located in room A and during the afternoon in room B while another test subject was in the opposite room. The full structure of one day of testing is shown in Table 3.

Table 3. Structure of a test day.

Time	Activity
9:00 HR	Test subjects arrives at SBi
9:00 to 9:30 HR	Information, coffee/tea, filling in part 1 of questionnaire
9:30 to 11:50 HR	The morning period of the test, test subject in room A (B) Test subjects were asked to do standard office work, If they felt too warm they could open the square sized window in the façade
11:50 to 12:00 HR	Filling in part 2 of questionnaire
12:45 to 15:30 HR	The afternoon period of the test, test subject in room B (A) Test subjects were asked to do standard office work, If they felt too warm they could open the square sized window in the façade
15:30 to 15:45 HR	Filling in part 3 and 4 of questionnaire
15:45 to 16:00 HR	Closing, cleaning up

Structure of questionnaire

The questionnaire survey is divided in 4 parts. The 1st part contains general information on the test subject, like age, gender, and if the test subject would describe him- or herself as being sensitive to bright light.

The 2nd and 3rd part contains questions regarding the visual environment in the test room. The two questionnaires are similar, with the only difference being the room evaluated and time of day when filling in the questionnaire.

Key questions

The key question on how the patterns influence on the view through the window is given below. The question is structured with an overall question, with sub questions (a–f) to be answered on a 5 point ordinal scale. The questions are asked for the upper and lower part of the window separately.

> How do you experience that the pattern in the upper/lower part of the window influences the view?
>
> a. When I look through the pattern the view is? An answer could be given on a 5 point ordinal scale from “Blurred” to “Clear”
>
> b. Objects outside are? An answer could be given on a 5 point ordinal scale from “Changed” to “Natural”
>
> c. When I look through the pattern it is? An answer could be given on a 5 point ordinal scale from “Uncomfortable” to “Comfortable”
>
> d. Colours on external objects have? An answer could be given on a 5 point ordinal scale from “Changed” to “Natural”
>
> e. The pattern in the window is? An answer could be given on a 5 point ordinal scale from “Unacceptable” to “Acceptable”
>
> f. When I look through the pattern the view is? An answer could be given on a 5 point ordinal scale from “Tranquil” to “Flicker”

Another key question included in the 2nd and 3rd part of the questionnaire concerns the indoor climate of the room. On a 5 point nominal scale the test subject were to evaluate if they were “Very unsatisfied”, “Unsatisfied”, “Neither unsatisfied or satisfied”, “Satisfied”, or “Very satisfied” with the room temperature, air quality, noise, glare, and daylight conditions. The central answers for this investigation are the ones dealing with glare and daylight, and these are to be analysed in the result section.

The 4th part is a comparison of the two rooms, where the test subjects compare the two rooms through questions. The following questions are evaluated in this report:

- Which room do you find brightest?
- Which room do you like the most?
- In which room do you find the pattern in the façade to be most acceptable?
- Which room would you choose if you were asked to be in the room for an entire day?

For each question the possible answers were given on a nominal scale: “Room A”, “Room B”, “Both Room A and B”, or “None”.

Statistics - questionnaire survey

The experiments are performed as a within group experiment, where the same test subject was evaluating both the panel in Room A and in Room B. A test subject could either start out in Room A or Room B. The test was in this way balanced and the statistical test used was the non-parametric statistics for two related samples. The evaluation of a room in the morning by one subject was hereby related to the same subject's evaluation of the other room in the afternoon.

The test applied was the Wilcoxon matched-pairs signed-ranks test with the significance level of 0.05. The sample size (*N*) was 19 for each test (test 1 and 2).

Results

Test 1, Measurement result

Work-field illumination

The average workfield illumination being measured as a mean of sensor 2 and 5, during the 1st test is shown graphically in Figure 7, morning and Figure 8, afternoon:

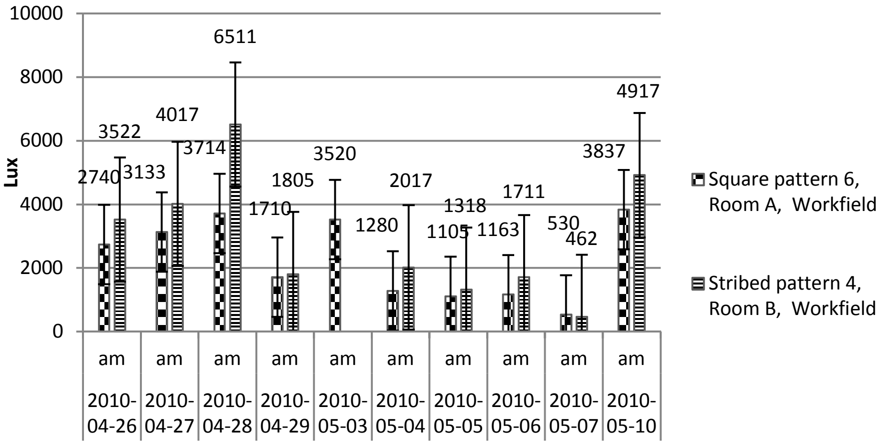


Figure 7. Average illumination on the workfield during experiment 1 in the morning. I.e. the average of the horizontal measured light during experiment 1 by sensor 2 and 5. The bars are the standard deviation of the morning averages per treatment (pattern).

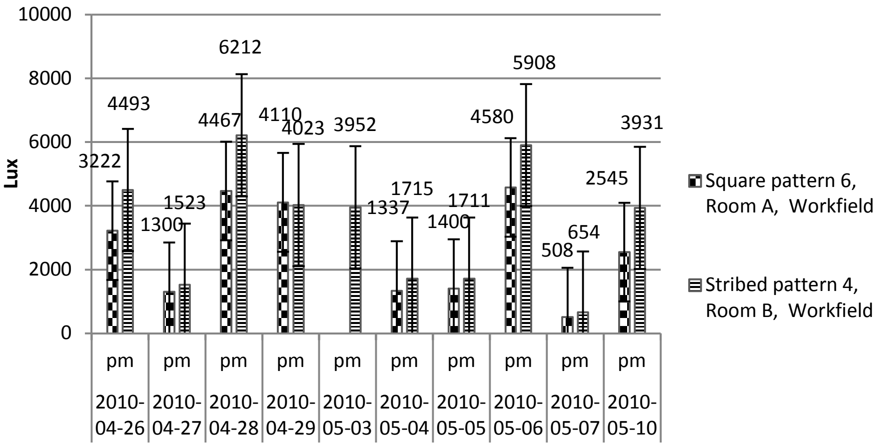


Figure 8. Average illumination on the workfield during experiment 1 in the afternoon. I.e. the average of the horizontal measured light during experiment 1 by sensor 2 and 5. The bars are the standard deviation of the averages shown per treatment (pattern).

In 8/10 mornings and afternoons, respectively, the average illumination on the workfield in room B, striped pattern 4, was above what was found in room A, square pattern 6 (Figure 7 and Figure 8).
The average of the mean values presented in Figure 7 and Figure 8 above is shown in Figure 9.

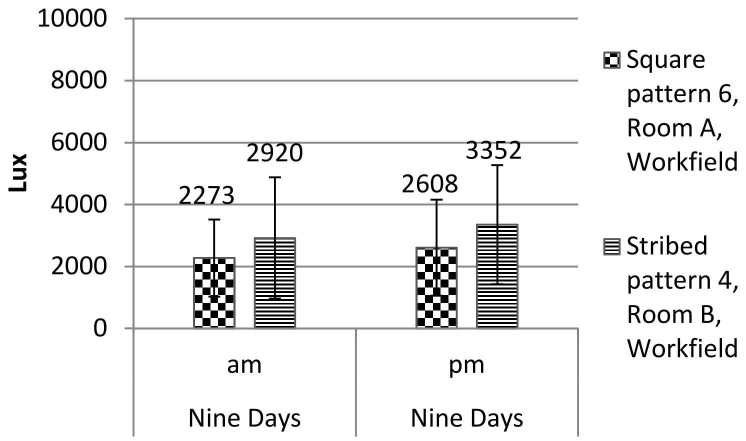


Figure 9. Average illumination on the workfield during experiment 1 in the morning and afternoon, respectively. The bars are the standard deviation of the averages for nine days included.

There was no significant effect of period (p=0,34; NS) when the average illumination in the workfield was analyzed using the explanatory variable test-panel-treatment (T) and period (P) and with random effect of test person. When only T was included in the test as explanatory variable there was no effect of the test-panel-treatment (p=0,094; NS), i.e. there was no significant difference between the average illumination in the workfield between the treatments (pattern 4 and 6, see Table 4).

Table 4. Test 1 result of the average workfield illumination (i.e. average of sensor 2 and 5) analysis for treatment effects. No significant effects were found.

Test period	Proc mixed model explanatory variables	Variable effect, P-values	Pattern #: Least Square Means	LSM difference, test result	± std. error.
1	T	p=0,1054 NS	4: 3168	a	
	P	p=0,3437 NS	6: 2443	a	±380
	T	p=0,0942 NS	4: 3179	a	
			6: 2432	a	±380

Indirect vertical illumination measured on the sidewalls

The average indirect illumination on the sidewalls being measured as a mean of sensor 8 and 9 in the morning (Figure 10), and a mean of sensor 6 and 7 in the afternoon (Figure 11) during the 1st test is shown graphically.

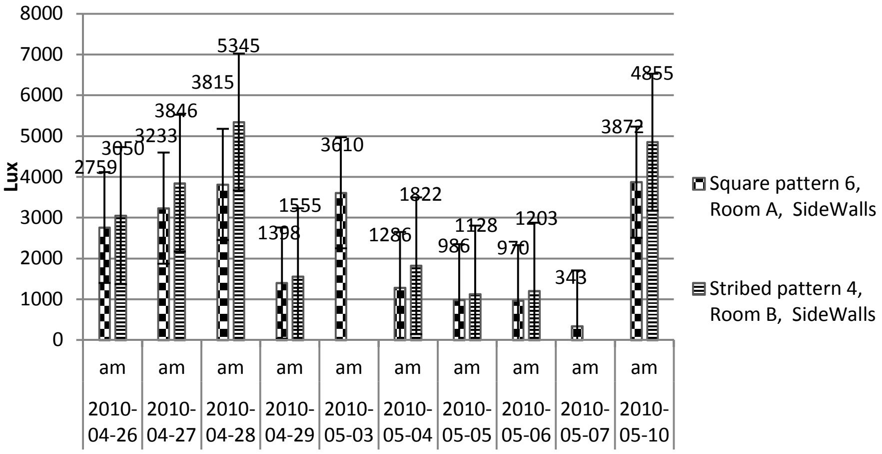


Figure 10. Average indirect illumination on the sidewalls during experiment 1 in the morning. I.e. the average of the vertical measured light during experiment 1 by sensor 8 and 9 from 09:45 to 11:45 HR. The bars are the standard deviation of the averages shown per treatment (pattern). On May 7th 2010 one sensor in room B had fallen down on the floor and data therefore discarded.

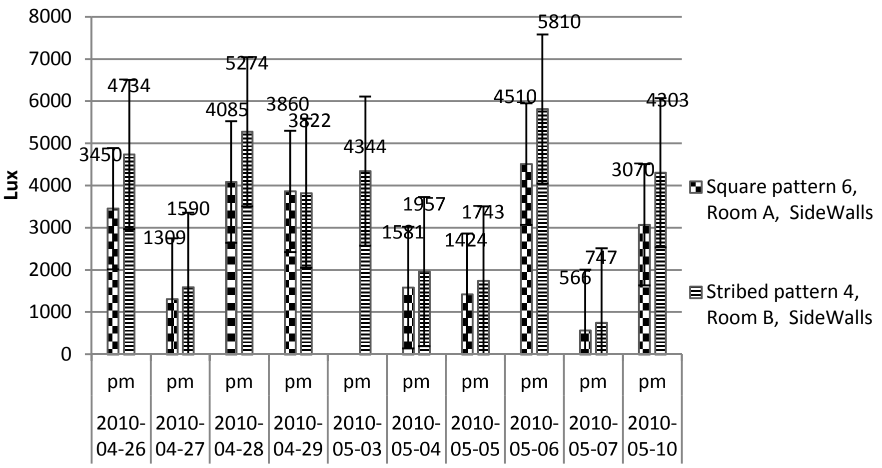


Figure 11. Average indirect illumination on the sidewalls during experiment 1 in the afternoon. I.e. the average of the vertical measured light during experiment 1 by sensor 6 and 7 from 09:45 to 11:45 HR. The bars are the standard deviation of the averages shown per treatment (pattern).

In 8/10 mornings and afternoons, respectively, the average indirect illumination on the sidewall in room B, striped pattern 4, was above what was found in room A, square pattern 6 (Figure 10 and Figure 11).
The average of the mean values presented in Figure 10 and Figure 11 above is shown in Figure 12.

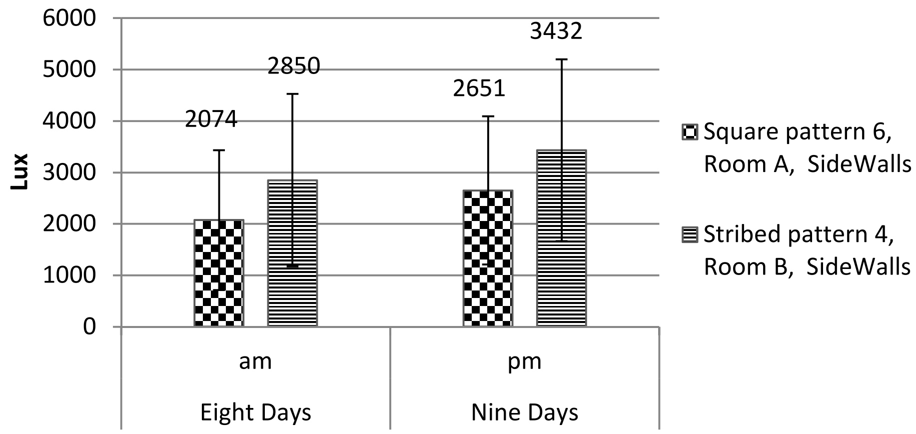


Figure 12. Average indirect illumination on the sidewalls during experiment 1 in the morning and afternoon, respectively. The bars are the standard deviation of the averages for days/periods included.

There was no significant effect of period (p=0.23; NS) when the average indirect illumination on the sidewalls per period was analyzed using the explanatory variable test-panel-treatment (T) and period (P) and with random effect of test person. When only T was included in the test as explanatory variable there was no effect of the test-panel-treatment (p=0.12; NS), i.e. there was no significant difference between the average indirect illumination on the sidewalls per period between the treatments (pattern 4 and 6). The estimates were for pattern 4 = 3148 ± 363, and for pattern 6 = 2428 ± 354 (Table 5).

Table 5. Test 1 result of the analysis for treatment effects concerning the average indirect illumination on the sidewalls per period. No significant effects were found.

Test period	Proc mixed model explanatory variables	Variable effect, P-values	Pattern #: Least Square Means	LSM difference, test result	± std. error.
2	T	p=0.1420 NS	4: 3110	a	±363
	P	p=0.2329 NS	6: 2441	a	±354
	T	p=0.1213 NS	4: 3148	a	±363
			6: 2428	a	±354

Relationship between horizontal and vertical illumination

The horizontal illumination measured on the workdesk (Workdesk lux) as a percentage of Workdesk lux and Sidewall lux was found in order to describe the light distribution in the rooms. These average % of the horizontal light on the workdesk per period, i.e. morning and afternoon was calculated (data not shown) and the overall means per period, with the standard errors are shown in Figure 13.

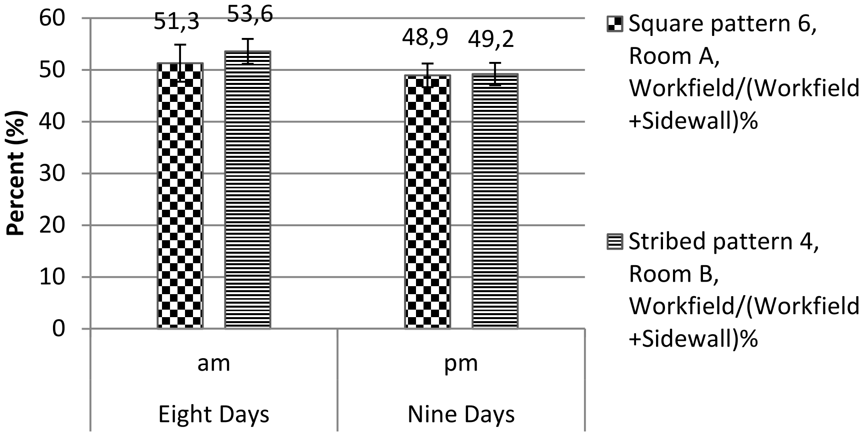


Figure 13. The average horizontal illumination measured on the workdesk as a percentage of the average illumination on the workdesk and the vertical indirect illumination on the sidewalls. The bars are the standard errors per period.

Against light and background light

The result of the analysis for the against light (sensor 3) and background light (sensor 4) during test 1 showed a similar result as for the horizontal illumination measured on the workdesk (Figure 9) and the vertical indirect illumination on the sidewalls (Figure 12), displaying more illumination in room B, striped pattern 4 versus what was found in room A, square pattern 6.

The average of the mean values found per period for the *against light* (sensor 3) in the morning was 5679 lux in room A, square pattern 6 and 7396 lux in room B, striped pattern 4. In the afternoon the average illuminations found were 6887 and 8976 lux for room A and B, respectively.

The average of the mean values found per period for the *background light* (sensor 4) in the morning was 1050 lux in room A, square pattern 6 and 1355 lux in room B, striped pattern 4. In the afternoon the average illuminations found were 1297 and 1434 lux for room A and B, respectively. This equals 18.5 and 18.3% of the against light in the morning and 18.8 and 16.0% of the against light in the afternoon for room A and B, respectively.

Test 1, Questionnaires result

Evaluation of patterns

The figures below show the mean score and standard deviation given for the 6 questions considering the view through the upper and lower part of the patterns in the window.

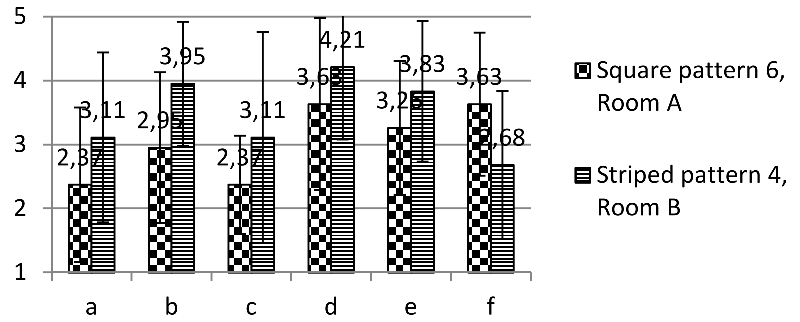


Figure 14. Mean value and standard deviation for evaluation of questions regarding the view through the pattern in the upper part of the window.

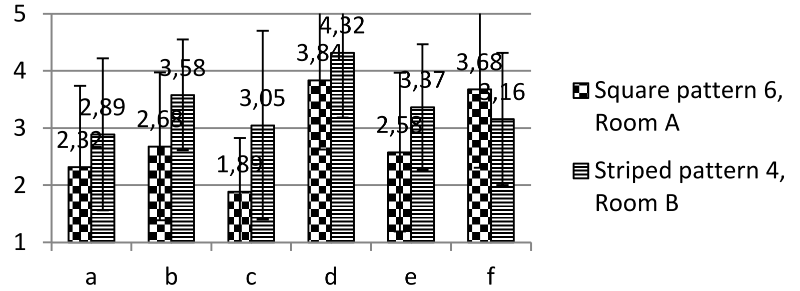


Figure 15. Mean value and standard deviation for evaluation of questions regarding the view through the pattern in the lower part of the window.

Table 6. The question, answer option and the description of the analyse results for the upper and lower window part in the 1st test. The sample size was 19 (N=19). The estimates are shown in Figure 14 and Figure 15.

Question:	Answer option (5 point ordinal scale)	Result description Upper window part	Result description Lower window part
a. When I look through the pattern the view is?	1="Blurred" to 5="Clear"	The view through the square pattern 6 in room A was evaluated more blurred compared to the striped pattern 4 in room B. (p=0,034)	No statistical difference observed between the views through the square pattern 6 in room A vs. the striped pattern 4 in room B. (NS)
b. Objects outside are?	1="Changed" to 5="Natural"	The objects outside are evaluated more close to natural through the striped pattern 4 in room B vs. the square pattern 6 in room A. (p=0,001)	Similar result as for the upper window part (p=0,002)
c. When I look through the pattern it is?	1="Uncomfortable" to 5="Comfortable"	The look through the square pattern 6 in room A was evaluated being more uncomfortable compared to the striped pattern 4 in room B. (p=0.015)	Similar result as for the upper window part (p=0.013)
d. Colours on external objects have?	1="Changed" to 5="Natural"	No significant difference between the evaluations of colours on external objects (NS)	Colours on external objects were evaluated more natural in Room B, pattern 4 compared to objects seen through pattern 6 in Room A (p=0.03).
e. The pattern in the window is?	1="Unacceptable" to 5="Acceptable"	No significant difference in the evaluations. The average answers showed that both patterns were just acceptable. (NS)	No significant difference in the evaluations. The average answers show that pattern 6 in room A was just unacceptable whereas pattern 4 in room B was just acceptable, however close to neutral. (NS)
f. When I look through the pattern the view is?	1="Tranquil" to 5="Flickery"	The look through the square pattern 6 in room A was evaluated more flickery compared to the pattern 4 in room B. Pattern 4 in room B is in average evaluated just a little more Tranquil than Flickery. (p=0.022)	No significant difference in the evaluations. Both patterns were in average evaluated more Flickery than Tranquil. (NS)

Evaluation of daylight level and glare

The evaluation of glare in the rooms and amount daylight within the room showed no significant difference between the evaluations in the mornings and afternoons as well as there was found no significant difference between the evaluation of glare and daylight level in the two rooms. The general trend both in terms of daylight and evaluation of glare is that the test subjects rated both parameters with a mean score around 4, which means that they were satisfied with the conditions.

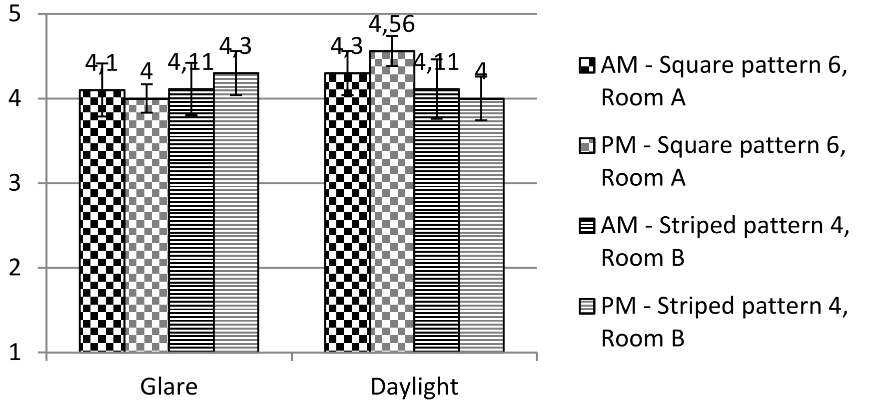


Figure 16. Glare and Daylight level inside the room was evaluated on a 5-point nominal scale. Ranging from 1 = “Very unsatisfied”, 2 =“Unsatisfied”, 3 = “Neither unsatisfied nor satisfied”, 4 = “Satisfied”, to 5 = “Very satisfied”, the figure shows the mean score of the evaluations, with bars showing the standard errors.

The frequency graph below shows that the test subjects were not bothered by glare from the window.
The test subjects were given the choice to use the internal venetian blind, if they wanted to.

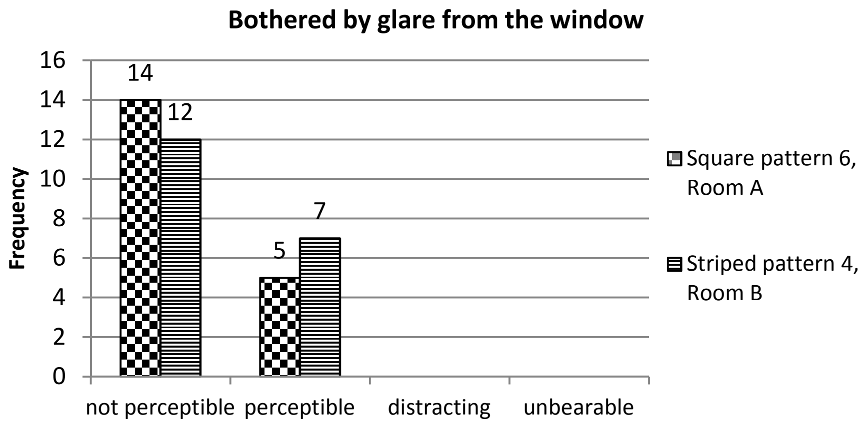


Figure 17. Frequency graph showing the test subjects evaluation of; if they were bothered by glare from the window.

Comparing the two test-rooms, pattern 4 and 6

The following 4 figures (Figure 18 - Figure 21) shows that the test subjects prefer the striped pattern in Room B which was evaluated more bright opposed to Room A with the square pattern.

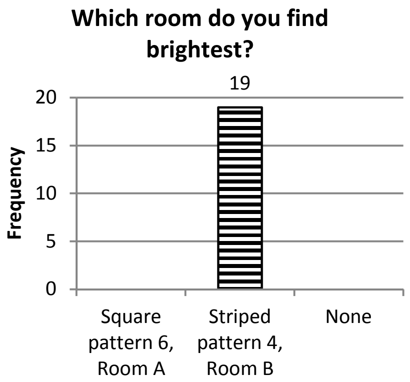


Figure 18. Frequency graph showing which room the test subjects evaluates as brightest.

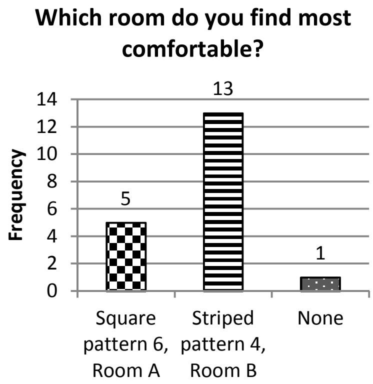


Figure 19. Frequency graph showing which room the test subjects finds most comfortable

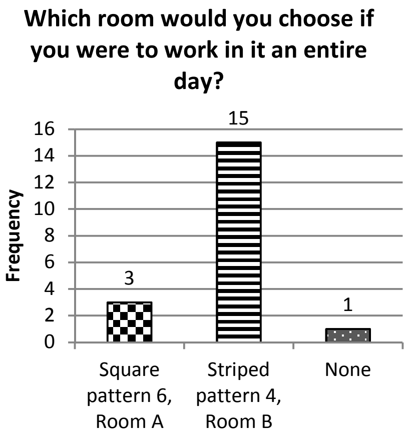


Figure 20. Frequency graph showing the room the test subjects would prefer, if they were to work in it for the entire day.

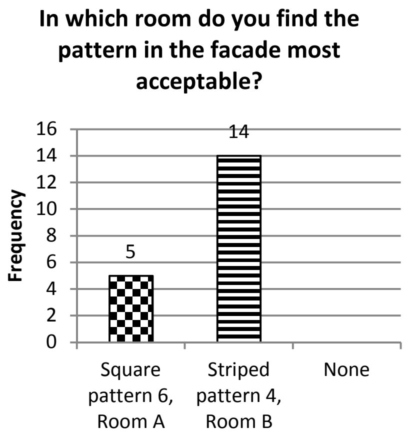


Figure 21. Frequency graph showing which room the test subjects finds the pattern most acceptable.

Test 2, Measurement result

Work-field illumination

The average workfield illumination being measured as a mean of sensor 2 and 5, during the 2nd test is shown graphically in Figure 22, morning and Figure 23, afternoon:

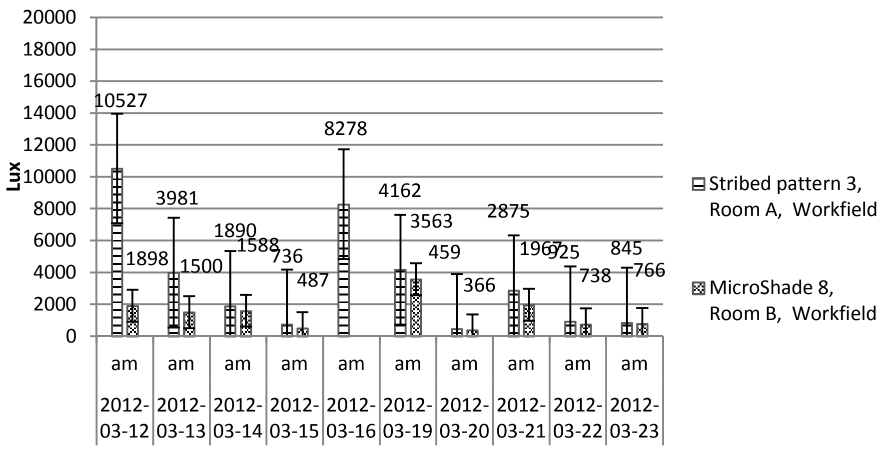


Figure 22. Average illumination on the workfield during the 2nd test in the morning. I.e. the average of the horizontal measured light during experiment 2 by sensor 2 and 5. The bars are the standard deviation of the averages shown per treatment (pattern).

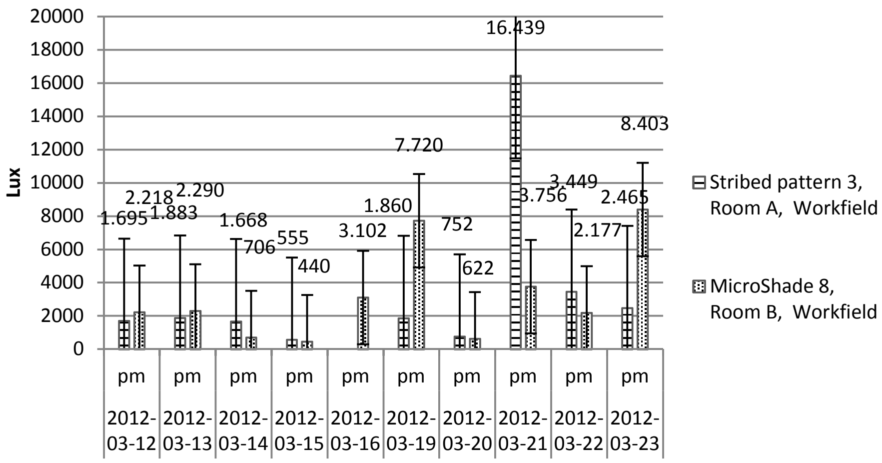


Figure 23. Average illumination on the workfield during the 2nd test in the afternoon. I.e. the average of the horizontal measured light during experiment 2 by sensor 2 and 5. The bars are the standard deviation of the averages shown per treatment (pattern).

In 9 out of 10 of mornings the average illumination on the workfield in room A, striped pattern 3, was above what was found in room B, MicroShade 8 (Figure 22). The use of blinds to avoid glare from the sun was determining the light on the workfield during the afternoon resulting in the variations between the average afternoon workfield illuminations measured (Figure 23).

The average of the mean values presented in Figure 22 and Figure 23 above is shown in Figure 24. The standard deviations are largest in room A, striped pattern 3 indicating a larger variation in the light intensity on the workfield in room A opposed to room B.

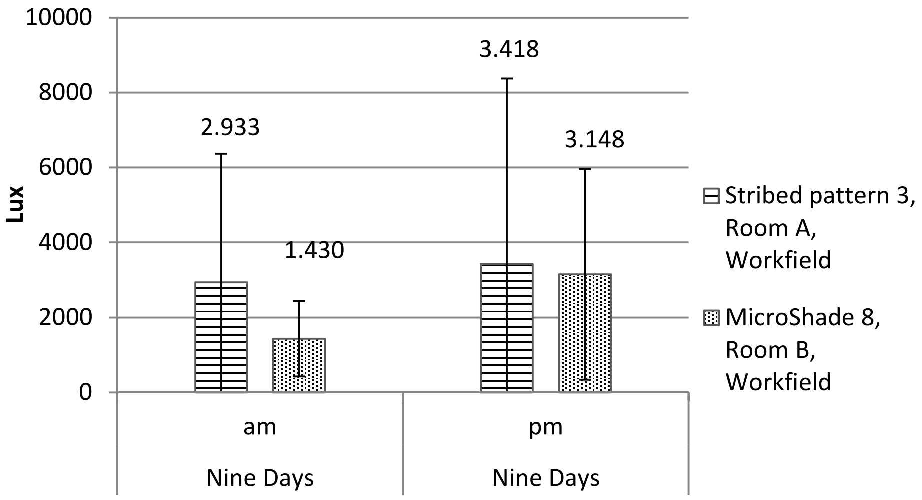


Figure 24. Average illumination on the workfield during the 2nd test in the morning and afternoon, respectively. The bars are the standard deviation of the averages for nine days included.

There was no significant effect of period (p=0,44; NS) when the average illumination in the workfield was analyzed using the explanatory variable test-panel-treatment (T) and period (P) and with random effect of test person. When only T was included in the test as explanatory variable there was no effect of the test-panel-treatment (p=0,30; NS), i.e. there was no significant difference between the average illumination in the workfield between the treatments (pattern 3 and MS). The estimates were for pattern 3 = 3444 ±761, and for pattern MS = 2332 ±761 (Table 7. Test 2 result of the average workfield illumination (i.e. average of sensor 2 and 5) analysis for treatment effects. No significant effects were found.).

Table 7. Test 2 result of the average workfield illumination (i.e. average of sensor 2 and 5) analysis for treatment effects. No significant effects were found.

Test period	Proc mixed model explanatory variables	Variable effect, P-values	Pattern #: Least Square Means	LSM difference, test result	± std. error.
2	T	p=0,2884 NS	3: 3466	a	
	P	p=0,4414 NS	MS: 2310	a	±765
	T	p=0,3000 NS	3: 3444	a	
			MS: 2332	a	±761

Indirect vertical illumination measured on the sidewalls

The average indirect illumination on the sidewalls being measured as a mean of sensor 8 and 9 in the morning (Figure 25), and a mean of sensor 8 and 9 in the afternoon (Figure 26) during the 2nd test is shown graphically.

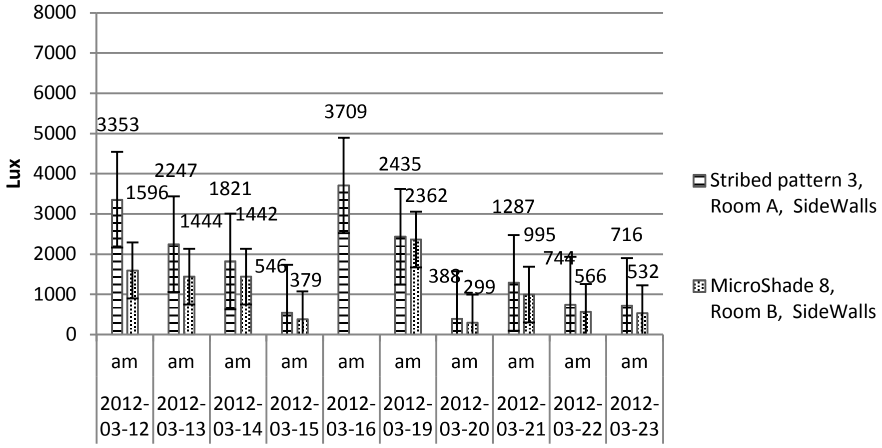


Figure 25. Average indirect illumination on the sidewalls during the 2nd test in the morning. I.e. the average of the vertical measured light during experiment 2 by sensor 8 and 9 from 09:45 HR to 11:45 HR. The bars are the standard deviation of the averages shown per treatment (pattern).

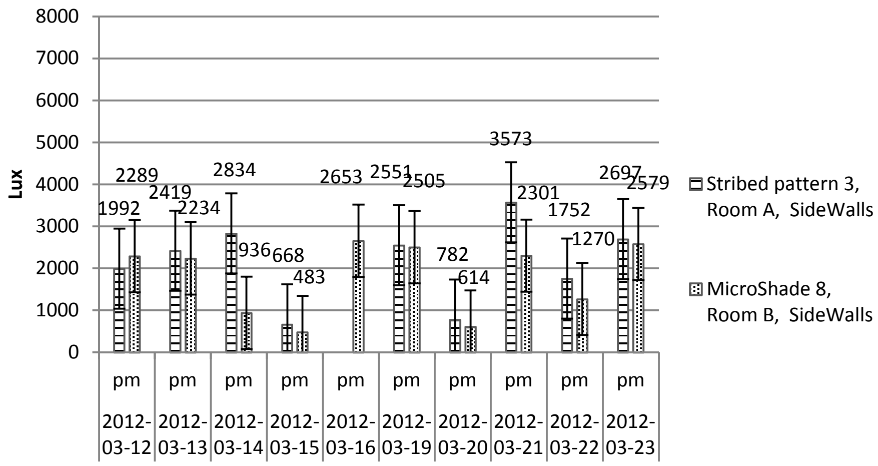


Figure 26. Average indirect illumination on the sidewalls during the 2nd test in the afternoon. I.e. the average of the vertical measured light during experiment 2 by sensor 6 and 7 from 13:00 HR to 15:30 HR. The bars are the standard deviation of the averages shown per treatment (pattern).

In 9 out of 10 mornings the average indirect illumination on the sidewalls in room A, striped pattern 3, was above what was found in room B, MicroShade 8 (Figure 25). In 8 out of 10 of afternoons the average indirect illumination on the sidewalls in room A, striped pattern 3, was above what was found in room B, MicroShade 8 (Figure 26).

The average of the mean values presented in Figure 25 and Figure 26 above is shown in Figure 27.

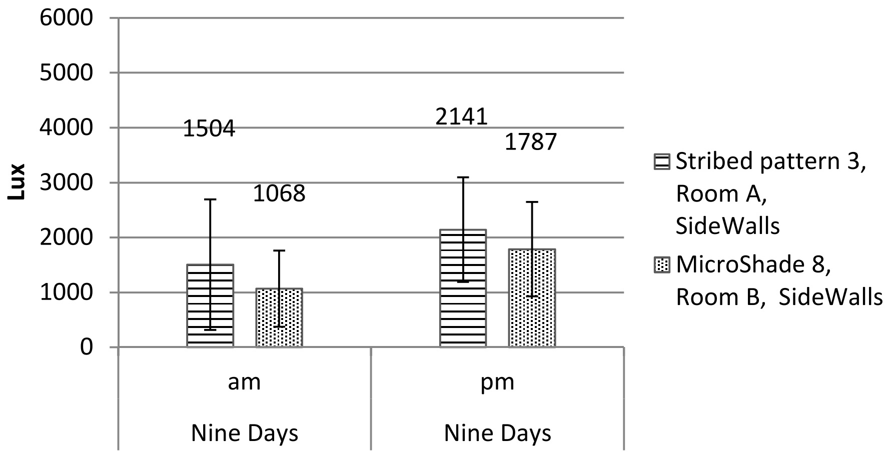


Figure 27. Average indirect illumination on the sidewalls during the 2nd test in the morning and afternoon, respectively. The bars are the standard deviation of the averages for days included.

There was significant effect of both test-panel-treatment (p= 0.025*) and period (p= 0,0134*) when the average indirect illumination on the sidewalls per period was analyzed using the explanatory variable test-panel-treatment (T) and period (P) and with random effect of test person. However, when only T was included in the test as explanatory variable there was no significant effect of the test-panel-treatment (p= 0.063 NS), i.e. there was no significant difference between the average indirect illumination on the sidewalls per period between the treatments (pattern 3 and MicroShade 8). The estimates were for pattern 3 = 1922 ± 222, and for MicroShade 8 = 1446 ± 222 (Table 8. Test 2 result of the analysis for treatment effects concerning the average indirect illumination on the sidewalls per period.).

Table 8. Test 2 result of the analysis for treatment effects concerning the average indirect illumination on the sidewalls per period.

Test period	Proc mixed model explanatory variables	Variable effect, P-values	Pattern #: Least Square Means	LSM difference, test result	± std. error.
2	T	p=0,0250 *	3: 1937	a	
	P	p=0,0134 *	MS: 1431	a	±213
	T	p=0,0631 NS	3: 1922	a	
			MS: 1446	a	±222

Relationship between horizontal and vertical illumination

The horizontal illumination measured on the workdesk (Workdesk lux) as a percentage of Workdesk lux and Sidewall lux was found in order to describe the light distribution in the rooms. These average % of the horizontal light on the workdesk per period, i.e. morning and afternoon was calculated (data not shown) and the overall means per period, with the standard errors are shown in Figure 28.

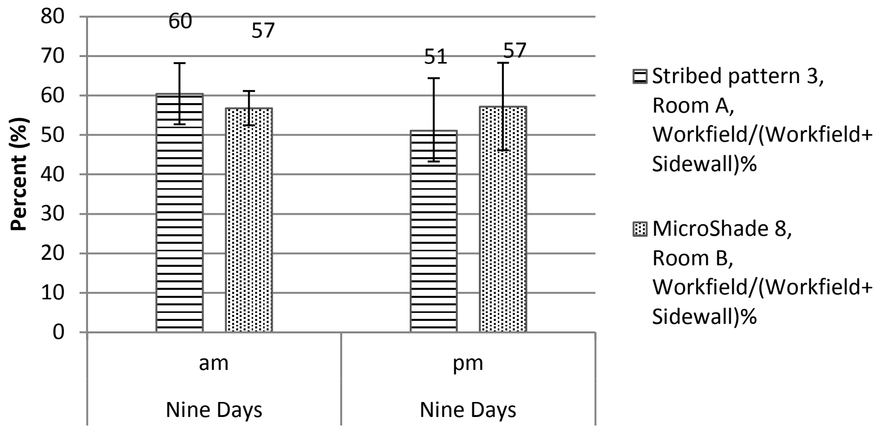


Figure 28. The average horizontal illumination measured on the workdesk as a percentage of the average illumination on the workdesk and the vertical indirect illumination on the sidewalls. The bars are the standard errors per period.

Relative to the general illuminance level there was lighter on the workdesk in room A, striped pattern 3 compared to room B MicroShade 8 during the mornings, whereas the trend changes in the afternoon. However these findings depend on the use and position of the blinds.

Against light and background light

The result of the analysis for the against light (sensor 3) and background light (sensor 4) during test 2 supports the result as for the horizontal illumination measured on the workdesk (Figure 24), displaying more illumination in room A, striped pattern 3 versus what was found in room B, MicroShade 8, in the morning. However, the average trend during the afternoon was showing equal or a little more light in room B, MicroShade 8 which was opposite to the morning situation. The afternoon light distribution depended much upon the use of blinds as for the illumination on the workdesk.

The average of the mean values found per period for the *against light* (sensor 3) in the morning was 6736 lux in room A, striped pattern 3 and 3933 lux in room B, MicroShade 8. In the afternoon the average illuminations found were 6076 and 6616 lux for room A and B, respectively.

The average of the mean values found per period for the *background light* (sensor 4) in the morning was 858 lux in room A, striped pattern 3 and 642 lux in room B, MicroShade 8. In the afternoon the average illuminations found were 1123 and 1215 lux for room A and B, respectively. This equals 12.7 and 16.3% of the against light in the morning and 18.5 and 18.4% of the against light in the afternoon for room A and B, respectively.

Test 2, Questionnaires result

Evaluation of patterns

As for the Test 1, the figure below shows the mean score and standard deviation given for the 6 questions considering the view through the upper part of the patterns in the window. The data were tested for difference in evaluations in the mornings and in the afternoons. This was done as a two independent samples test. The analysis showed no significant difference between the evaluations in the mornings and in the afternoons. Therefore the data could be analysed as related samples, and the evaluation of a room in the morning by one subject could be related to the same subject's evaluation of the other room in the afternoon.

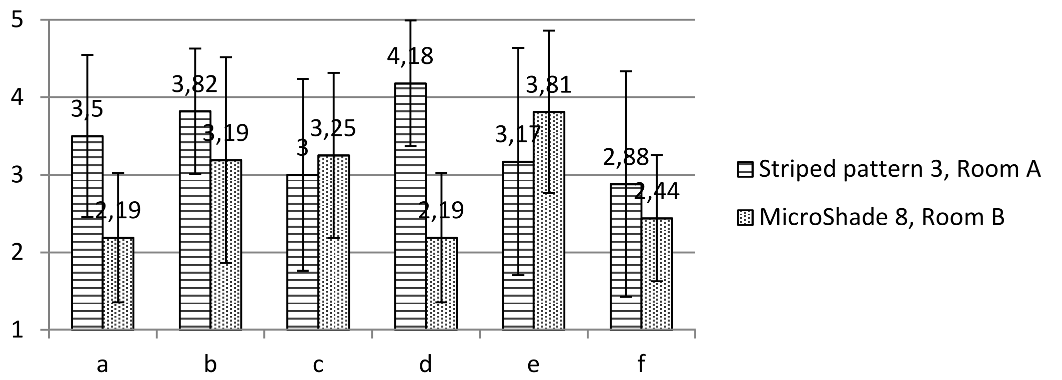


Figure 29. Mean value and standard deviation for evaluation of questions regarding the view through the pattern in the upper part of the window.

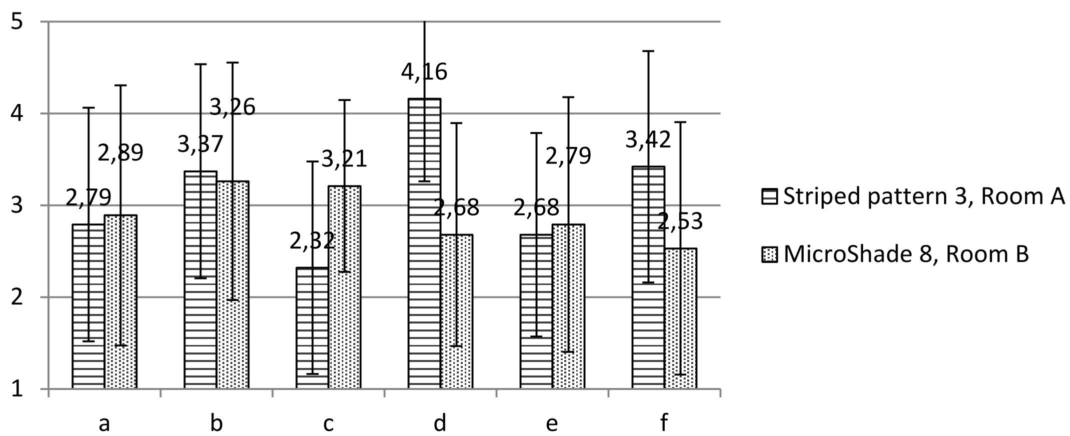


Figure 30. Mean value and standard deviation for evaluation of questions regarding the view through the pattern in the window.

Table 9. The question, answer option and the description of the analyse results for the upper and lower window part in the 1st test. The sample size was 19 (*N*=19). The estimates are shown in Figure 29 and Figure 30.

Question:	Answer option (5 point ordinal scale)	Result description Upper window part	Result description Lower window part
a. When I look through the pattern the view is?	1="Blurred" to 5="Clear"	The view through pattern MS in room B was evaluated more blurred compared to pattern 3 in room A (p=0,004)	No significant difference was observed between the views through the MS pattern in room B vs. the striped pattern 3 in room B. (NS)
b. Objects outside are?	1="Changed" to 5="Natural"	No significant difference was found between the appearance of objects outside the MS pattern in room B vs. the appearance of objects outside the striped pattern 3 in room B. Both means turned out more "Natural" than "Changed" (NS)	Similar result as for the upper window part (NS)
c. When I look through the pattern it is?	1=" Uncomfortable" to 5="Comfortable"	No significant difference was found between the look through the pattern MS in room B compared to pattern 3 in room A. The look was neither uncomfortable nor comfortable (NS)	The look through pattern MS was in average found just comfortable whereas the look through the striped pattern 3 in room A was evaluated as uncomfortable and significantly different from the look through the MS pattern (p=0.018)
d. Colours on external objects have?	1="Changed" to 5="Natural"	The colours of the external objects were evaluated significantly more natural in room A, striped pattern 3, compared to the MS pattern in room B. (p=0,001)	Similar result as for the upper window part (p=0.001).
e. The pattern in the window is?	1=" Unacceptable" to 5="Acceptable"	No significant difference in the evaluations. The average answers showed that both patterns were just acceptable. (NS)	No significant difference in the evaluations. The average answers showed that both patterns were just unacceptable. (NS)
f. When I look through the pattern the view is?	1=" Tranquil" to 5=" Flickery"	No significant difference in the evaluations. Both patterns were in average evaluated more Tranquil than Flickery. (NS)	The look through the striped pattern 3 in room A was evaluated more flickery compared to the pattern MS in room B. Pattern MS in room B is in average evaluated just a little more Tranquil than Flickery. (p=0.023)

Evaluation of daylight level and glare

The evaluation of glare in the rooms and amount daylight within the room showed no significant difference between the evaluations in the mornings and afternoons as well as there was found no significant difference between the evaluation of glare and daylight level in the two rooms. The test subjects rated both daylight and glare conditions with a mean score between 3 and 4.3, which means that they were satisfied with the conditions (Figure 31).

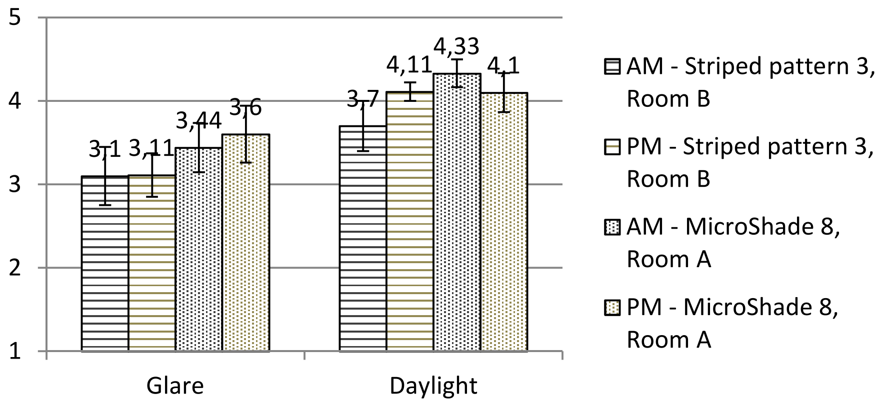


Figure 31. Glare and Daylight level inside the room was evaluated on a 5-point nominal scale. Ranging from 1 = "Very unsatisfied", 2 ="Unsatisfied", 3 = "Neither unsatisfied nor satisfied", 4 = "Satisfied", to 5 = "Very satisfied", the figure shows the mean score of the evaluations, with bars showing the standard errors.

Even though no significant evaluation of glare in terms of satisfaction was found between the two rooms, it can be seen from the frequency graph on Figure 32 that twice as many test subjects (6 opposed to 3) evaluated they were bothered by glare from the window in Room A compared to Room B.

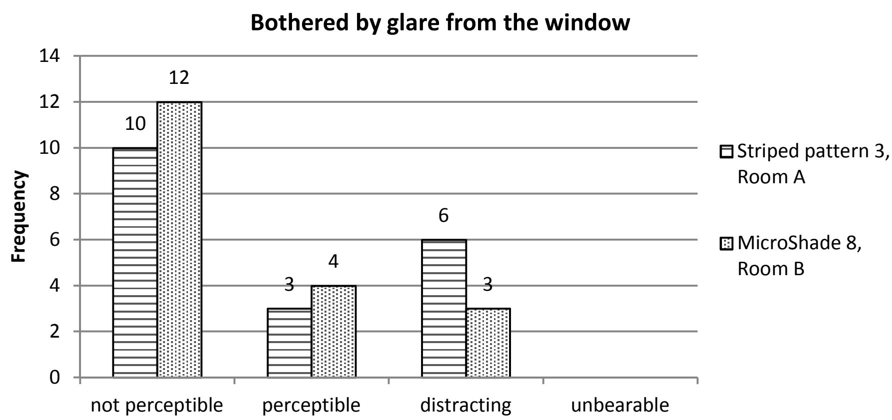


Figure 32. Frequency graph showing the test subjects evaluation of; if they were bothered by glare from the window.

Comparing pattern 3 and MicroShade

The following 4 figures (Figure 33 - Figure 36) show that the test subjects evaluates room A (pattern 3) as brightest and evaluate both rooms comfortable. If given the choice of working in one room opposed to the other for an entire day the majority of the test subjects prefer room B (MicroShade), i.e.

10 test subjects prefer Room B (MicroShade) opposed to 7 test subjects preferring Room A (pattern 3). Furthermore the pattern in the façade is being evaluated as most acceptable in Room B (MicroShade) by 11 test subjects opposed to 5 test subjects preferring Room A (pattern 3).

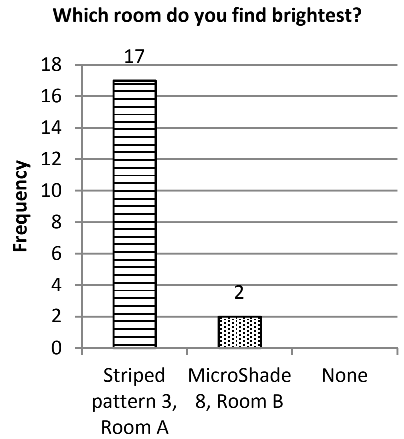


Figure 33. Frequency graph showing which room the test subject evaluates as brightest

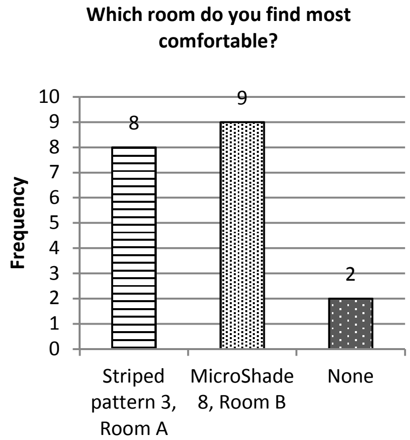


Figure 34. Frequency graph showing which room the test subject finds most comfortable

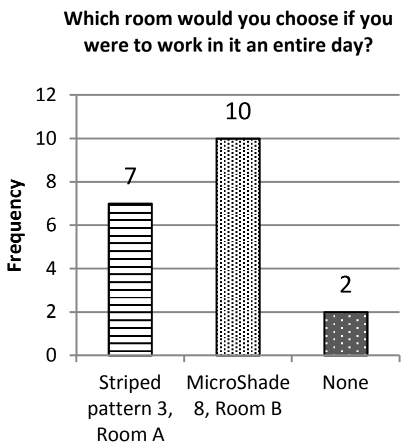


Figure 35. Frequency graph showing the room the test subjects would prefer, if they were to work in it for an entire day

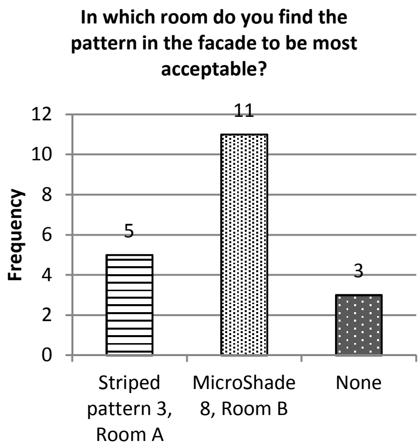


Figure 36. Frequency graph showing which room the test subjects finds the pattern most acceptable

Result of Test 1 and 2

Measurement result

Workfield illumination

When the averages of the illumination on the workfield for test 1 and 2 (4 different patters) per period (P), i.e. morning and afternoon workfield illumination, was analysed with the Period (P) and test-panel-treatment (T) as the explanatory variables and test subjects (person) included as random effect, then no effect of P (p=0.2752 NS) and T (0.4134 NS) was found. By excluding P in the analysis there were no significant of T (p=0.4224 NS, Figure 37)

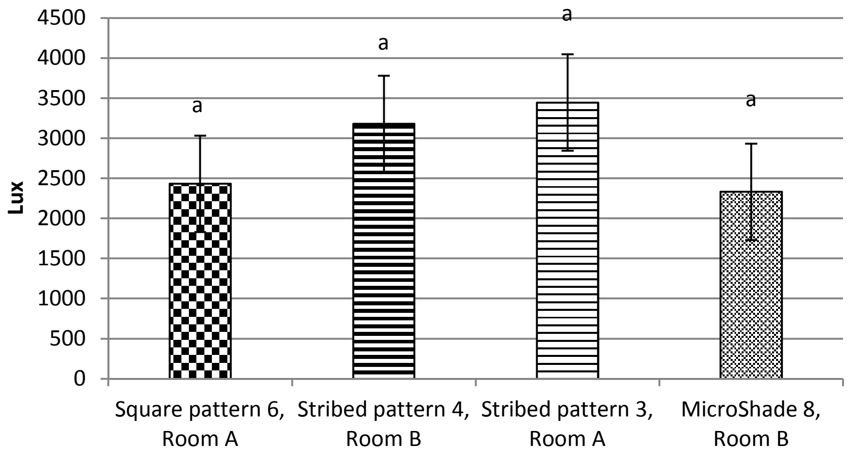


Figure 37. Average illumination on the workfield during test 1 and 2 with standard error bars. The averages of the illumination on the workfield per period (P), i.e. morning and afternoon illumination on the workfield, was analysed with the test-panel-treatment (T) as the explanatory variable and the test subjects (person) included as random effect. The mixed model procedure (PROC MIXED) of SAS was used for the computation (SAS Institute, Cary, NC). Identical lower case letters indicate no significant difference of the least square means.

Indirect illumination on the sidewalls

When the averages of the indirect illumination on the sidewalls for test 1 and 2 (4 different patters) per period (P), i.e. morning and afternoon workfield illumination, was analysed with the Period (P) and test-panel-treatment (T) as the explanatory variables and test subjects (person) included as random effect, then there were effects of both P (p=0.0221*) and T (0.0027**). By excluding P in the analyze there was significant of T (p=0.0025**, Figure 38)

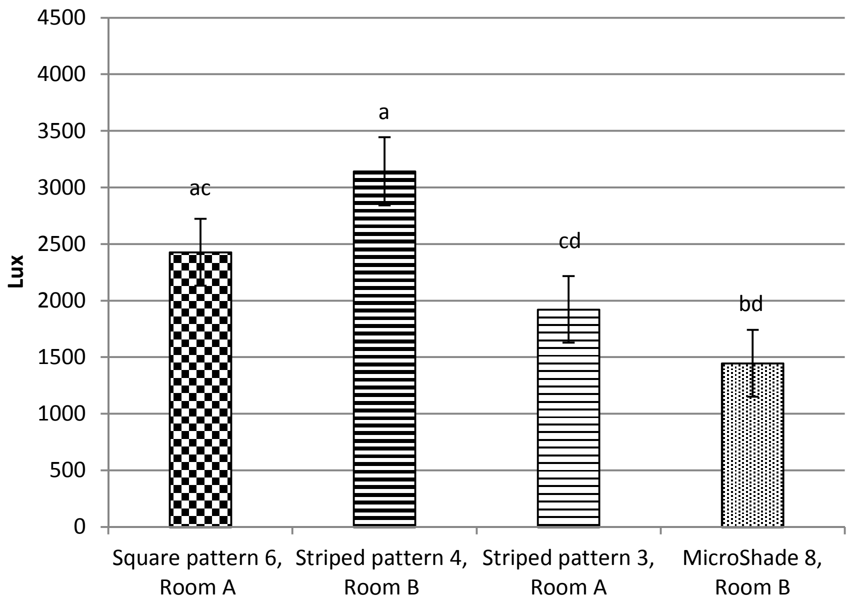


Figure 38. Estimated averages of the indirect illumination on the sidewalls during test 1 and 2 with standard error bars. The averages of the indirect illumination on the sidewalls per period (P), i.e. morning and afternoon illumination on the workfield, was analysed with the test-panel-treatment (T) as the explanatory variable and the test subjects (person) included as random effect. The mixed model procedure (PROC MIXED) of SAS was used for the computation (SAS Institute, Cary, NC). Identical lower case letters indicate no significant difference of the least square means.

Discussion

The tests procedure

To obtain statistical evidence user evaluations require often several people involved and they are therefore expensive, but user evaluations are often necessary because the perception of people differs. Nevertheless, the selection of panels for the first test was based on our own initial evaluation of the panels. We found that panels with square geometry were distorting the horizontal line more than the striped geometry and that a higher transparency towards the window in the middle therefore was preferable.
The panels for the 1st test was chosen as being two distinct patterns in terms of the geometry of the cells and transparency, but both resemble a similar structure with transparency increasing towards the middle window (Table 2). Based on the initial result from the 1st test showing a more positive evaluation of the dummy panel with the greatest transparency (Figure 18 to Figure 21), then panel 3 was chosen to be evaluated together with MicroShade in the second test. Panel 3 is very similar to panel 4 but having a slightly greater transparency than panel 4.

To support the results of the questionnaire survey we measured the light conditions both horizontally and vertically several strategically places in the rooms. The result of the light measurements is influenced by the test persons present in the rooms being allowed to change the conditions depending on their work tasks and preferences. This effect is included in the statistical analysis of the illumination as a random effect. However, the option that the test person had to freely regulate the internal venetian blind though influenced the illumination results. This occurred especially in the afternoon where the direct light was elsewise distracting the test person in the position behind the workdesk. The change of the room condition due to the test persons use (especially the blinds) is important to have in mind when evaluating the illumination results.

In general the same trends were seen in the comparisons of the upper and lower window part with the various patterns being tested (Table 6 and Table 9). The difference between the upper and lower window part is the background colour of the patterns, i.e. the view through the panels. The view through the lower patterns was to a green field with some details, whereas through the upper pattern the view was to the sky.

Test 1

Both during the morning and afternoon more light was measured on the workdesk and on the sidewalls in room B, striped pattern 4 opposed to room A, square pattern 6 (Figure 7 to Figure 12). This was expected considering that the striped pattern is more transparent, i.e. a transparency of 72% opposed to 34% transparency for the square pattern (Table 2).

During the 1st test no test persons were bothered by glare (Figure 17) and they were evaluating the daylight and glare condition fairly high, reaching a mean score just above 4=Satisfied (Figure 16).

The test subjects evaluated the view through the square pattern 6 as more blurred than the striped pattern 4 with the statistical analysis being significant for the upper panel (Figure 14, Table 6, question a). The colours on external objects through the lower window part are evaluated more natural for the striped pattern than the squared, although the mean score of the squared pattern was above 3.6 (Figure 14, Table 6, question d). The mean score for whether the pattern was acceptable or unacceptable was in favor of the striped pattern 4 being a little higher than the square pattern 6, thus both close to neutral (Figure 14, Table 6, question e). The overall picture favor the striped pattern 4 vs. the square pattern 6.

The test subjects prefer the striped pattern 4 opposed to the square pattern 6. The main reason for this is considered to be due to:

1) the striped pattern being more transparent (72% vs. 34%), thus more light was present in this room (Figure 7 to Figure 12)

2) the square pattern being more 'flickery' compared to the striped pattern (Figure 14 (f) and Figure 15 (f)), and

3) the square pattern blocks a larger part of the view than the striped pattern and the square pattern somehow steals the horizontal line which is better seen through the striped pattern (Table 2).

Moreover, the objects outside were in average evaluated as being more close to natural than changed and the look through the panel being more comfortable through the striped pattern 4 than the square pattern 6 (Figure 14, Table 6, question b and c).

Test 2

For the experiment made during spring 2012, the MicroShade pattern was evaluated up against the striped pattern 3.
The average illumination being measured showed higher light intensities present in the room with the striped pattern 3 vs. the room with MicroShade, both during the morning and afternoon. Some days much higher light intensities were measured during the 2nd test than during the 1st test (Figure 22, Figure 23, Figure 25 and Figure 26). The high light intensities on some days may cause that some test persons evaluated some distracting glare conditions during the test (Figure 32). However, the possibility of using the blinds does that the test persons were able to change the light conditions and thereby to avoid distracting glare. We found that the light distribution in the afternoon was influenced by the test subjects' use of the blinds.
The daylight and glare condition of the rooms was rated with a mean score above 3 which equal 'neither unsatisfied nor satisfied', although some people were distracted by glare (Figure 31, Figure 32).

The view through the MicroShade pattern in the upper window part was evaluated more blurred (obsessed to 'clear') than the striped pattern 3 (Figure 29, Table 9, question a). However, the look through the MicroShade panel in the lower window part was evaluated just comfortable and tranquil whereas the look through the striped pattern was evaluated as uncomfortable and just flickery and the result being significantly different from the MicroShade result (Figure 30, Table 9, question c and f). The difference in the view behind the upper and lower panel respectively might cause these differences, since the MicroShade seems to change the colour appearance of the objects outside when looking through the panels (Figure 29 and Figure 30, Table 9, question d)

The evaluations of visual environment by the test subjects showed that they found the room with the striped pattern brightest (Figure 33), which equal the measurement results of the light conditions. At the same time they would prefer to work in the room with the MicroShade pattern, if they were to work in the room for an entire day (Figure 35). Furthermore they also evaluated the pattern most acceptable in the room with MicroShade opposed to the striped pattern 3 (Figure 36). This may imply that there is a limit to how bright a room should be or alternatively that the light distribution in the room with Microshade is preferred.

MicroShade is designed specifically for the purpose of blocking the direct sun while maintaining the view through the shade. An indication of that MicroShade has this effect is found in appendix Figure 40 showing a much greater illuminance measured by sensor 3 (against light) during the afternoon in room B, MicroShade, vs. the illuminance measured at the parallel position in room A, striped pattern 3.
The altered light distribution in the room with MicroShade is experienced more acceptable opposed to that of the room with the striped pattern 3 by a greater number of test persons than vice versa (Figure 36).
The measurement results also indicate that the blinds were used more in the room with the striped pattern 3 vs. room B, MicroShade. This is partly reflected in greater standard deviations for especially the workdesk illumination (Figure 22 to Figure 24). The greater standard deviations reveal a greater light intensity variation and therefore an assumed greater need for using the internal venetian blind.

Comparing the two tests - all four panels
During test 1 the average horizontal illumination measured on the workdesk as a percentage of the sum of the average illumination on the workdesk and the vertical indirect illumination on the sidewalls was approximately 50% in both rooms both during the morning and afternoon (Figure 13).
There was a higher average illuminance measured during test 2 in room A, striped pattern 3 vs. room B, Microshade (Figure 22 to Figure 27). However, there was found to be relatively more light on the workdesk in room B, Microshade vs. that of room A, striped pattern 3. This is shown by a greater average horizontal illumination measured in the afternoon on the workdesk as a percentage of the sum of the average illumination on the workdesk and the vertical indirect illumination on the sidewalls (Figure 28). This greater percentage light on the workdesk might partly be explained by the MicroShade effect blocking some of the direct light and changing the light distribution in the room. But the light distribution during the afternoon is also very much dependent on the use of the blinds, to avoid glare.
The horizontal measured illumination on the workdesk is relative to the vertical measured illumination on the sidewalls a little greater in test 2 than in test 1 (Figure 37 and Figure 38). Somehow less light is measured on the sidewalls during the 2nd test vs. that of the 1st, although the estimated light on the workdesk for the different test panels is not significantly different (Figure 37).

The average illuminance level both horizontal and vertically measured, shows that the lowest average illuminance level is found in the room with the MicroShade pattern (Figure 37 and Figure 38). Nevertheless, this pattern is overall being evaluated more positive compared to the striped pattern 3, that is very similar to the striped pattern 4 used in the 1st test. Pattern 4 was though evaluated more positively than the Square pattern 6 (Figure 18 to Figure 21) and square pattern 6 was measured to have brighter illuminated sidewalls than the MicroShade (Figure 38, having in mind that it was during two different tests and time periods). Overall the MicroShade seems to be influencing the light environment positively compared to the dummy test panels tested. This might be due to the fact that the view through the MicroShade pattern is maintained, and the light intensity fluctuations are reduced because of the geometrical structure of the Micro-fins in the MicroShade panels (Figure 3 and Figure 4). The colour appearance of the objects outside does change when looking through the MicroShade panels, but since the structure of the micro-fins are so small then there does not really appear a pattern in the panels where the MicroShade has an effect. This seems to be an advantage and preferred. If structures of the transparent PV panels cannot be very small as for the MicroShade panels, then patterns, where the horizontal line and an undisturbed view to the outside without distracting glare is somehow maintained, seems to be preferred. The horizontal striped patterns tested in these tests were preferred over squared patterns.

Conclusion

In evaluating the panels tested by questionnaires, we found the same trend to be evident in comparison of panels in the upper and lower window part. This was found in both test 1 and 2.

Both during the morning and the afternoon more light was measured vertically and horizontally in room B, striped pattern 4 opposed to room A, square pattern 6 (test 1). This result corresponds to the transparency of the test panels and what was experienced by the test persons found through questionnaire evaluations.

During the 1st test no one was bothered by glare and the evaluation of the daylight and glare condition of the test rooms were reaching a high mean score equal to being satisfied or more than satisfied with the conditions.

The test persons prefer the striped pattern 4 opposed to the square pattern 6.

The average illumination being measured showed higher light intensities present in the room with the striped pattern 3 vs. the room with MicroShade, both during the morning and afternoon (test 2). This corresponds to what what was experienced by the test persons found through questionnaire evaluations.

Some days much higher light intensities were measured during the 2nd test than during the 1st test, and the light distribution during the afternoon especially during the 2nd test was influenced by the test persons' use of the internal venetian blinds.

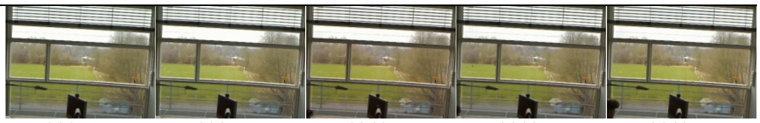
The MicroShade panels tested seems to change the colour appearance of the objects outside when looking through the panels, but most of the test persons prefer the room with the MicroShade panels vs. in the room with the striped pattern 3 if they were to work in the room for an entire day.

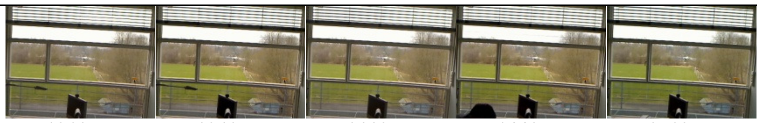
The lowest overall average illuminance was found in the room with MicroShade, but MicroShade was overall being evaluated more positive compared to the striped pattern 3, that is very similar to the striped pattern 4 used in the 1st test. The striped pattern 4 was though evaluated more positively than the Square pattern 6.

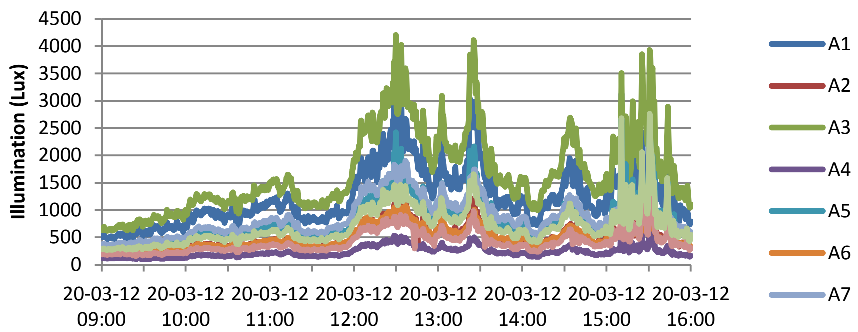
We found that if structures of the transparent PV panels cannot be very small as for the MicroShade panels, then patterns, where the horizontal line and an undisturbed view to the outside is somehow maintained, seems to be preferred. We conclude that the horizontal striped patterns tested in these tests were preferred over squared patterns. Moreover, MicroShade seems to influence the light environment positively compared to the dummy test panels. The view through the MicroShade panels is maintained (except for the color perception of objects outside) and the light intensity fluctuations and light intensity differences in the room seem to be reduced caused by the geometrical micro-structure perforations in the MicroShade panels.

Appendix

Table 10. Pictures takes during test 2 with the web cam showing examples of the light from the façade during the morning and afternoon on an overcast day (2012-03-20). The blinds were not regulated during the day.

Example of a morning period where the blinds are partly covering the upper panel in both room A and B.					
Striped pattern 3, Room A					
Time:	0937 HR	1007 HR	1037 HR	1107 HR	1137 HR
MicroShade 8, Room B					
Time:	0935 HR	1005 HR	1040 HR	1110 HR	1140 HR

Example of an afternoon period where the blinds are partly covering the upper panel in both room A and B.					
Striped pattern 3, Room A					
Time:	1307 HR	1337 HR	1407 HR	1437 HR	1507 HR
MicroShade 8, Room B					
Time:	1310 HR	1340 HR	1410 HR	1440 HR	1510 HR



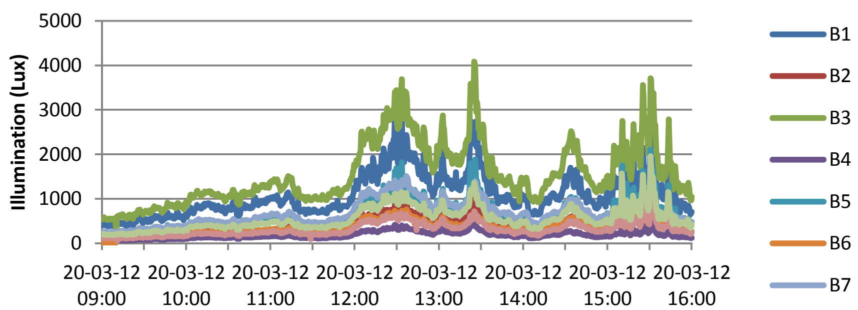
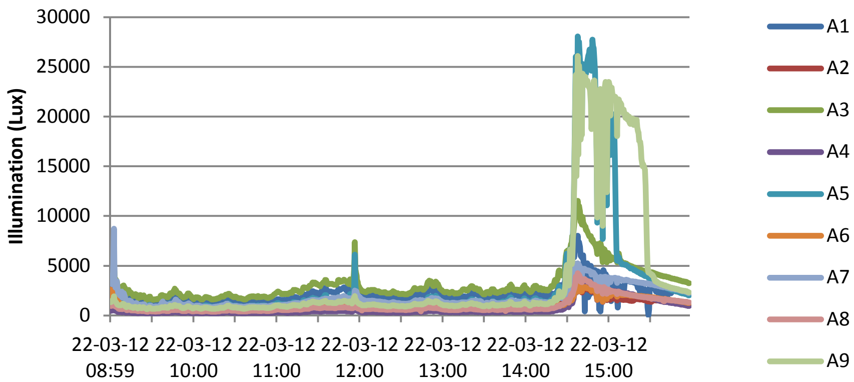


Figure 39. An example of the illumination on a fairly overcast day the 20th March 2012 measured by sensor 1-9 in room A (Striped pattern 3) and B (MicroShade 8), respectively. The blinds were partly covering the upper panel in both room A and B, however the blinds were not regulated during the day.

Table 11. Pictures takes during test 2 with the web cam showing examples of the light from the façade during the morning and afternoon on a day with few drifting clouds (2012-03-22). The blinds were not regulated during the day neither in room A or B.

Example of a morning period where the blinds are not used neither in room A or B.					
Striped pattern 3, Room A					
Time:	0935 HR	1005 HR	1035 HR	1105 HR	1135 HR
MicroShade 8, Room B					
Time:	0935 HR	1005 HR	1035 HR	1105 HR	1135 HR

Example of a morning period where the blinds are not used neither in room A or B.					
Striped pattern 3, Room A					
Time:	1305 HR	1335 HR	1405 HR	1435 HR	1505 HR
MicroShade 8, Room B					
Time:	1305 HR	1335 HR	1405 HR	1435 HR	1505 HR



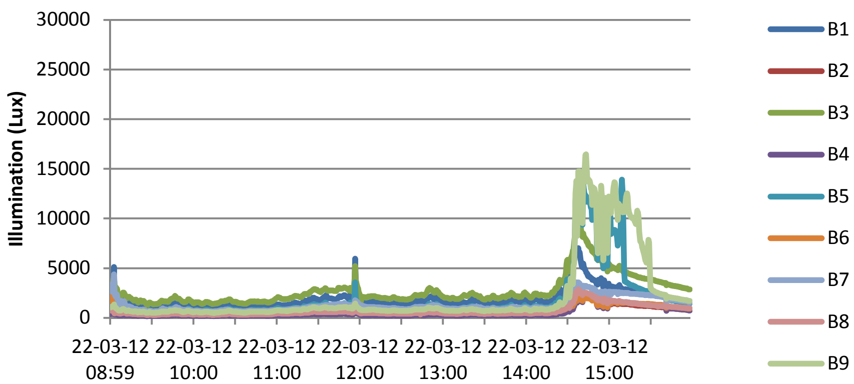


Figure 40. An example of the illumination on a day with drifting clouds the 22nd March 2012 measured by sensor 1-9 in room A (Striped pattern 3) and B (MicroShade 8), respectively.