New solar shading system based on daylight directing solar glass lamellas

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SUMMARY

This paper describes the development of a new solar shading system consisting of glass lamellas with a reflecting solar control coating. The coating is able to efficiently reduce the solar gain through building facades and at the same time redirect part of the daylight into the back of the room where it is most needed. The shading system has been simulated using IESve/Radiance on daylight conditions for a single cell office. A full-scale model of the shading system has also been tested in SBi's Daylight Laboratory. Simulations and measurements on the shading system under overcast conditions show a reduction in the daylight factor (DF) close to the facade while the DF is unchanged or even higher in the back of the office. Under sunny sky conditions, the lamellas will normally be turned into a vertical position. In this position, the reflective coating will contribute to reduce the heat load on the office significantly.

KEYWORDS

Solar shading, Indoor climate, Daylight factor, Visual comfort, Cooling/heating

INTRODUCTION

In buildings with large glass facades, it is necessary to use effective solar shading systems to be able to reduce energy consumption for ventilation and cooling. At the same time, there are demands both for optimising the use of daylight to fulfil a demand on a DF of 2% at the workplane and for reducing the energy use for artificial lighting.

The daylight level in window areas is often very high compared to the level in the back of the room in buildings with large room depths. In office buildings with glass facades, solar shading systems often consists of horizontal fixed lamellas made of opaque materials. Such shading systems effectively reduce the solar gain on the room, but they also spoil the view out of the window and reduce the daylight level in the room. Therefore, the need has come to develop effective solar shading systems being able to shield from direct sunshine close to the window area and at the same time being able to direct daylight into the back of the room. The system should also be able to maintain the view out of the window.

This paper describes a solar shading system set up with adjustable glass lamellas. The glass lamellas have a highly reflective coating on one side. The system is used as a normal solar shading system, which will reduce solar gains, and thus the cooling demands, but it also allows for higher daylight levels throughout the room compared to traditional shading systems due to the transparency of the glass. Tilted correctly the lamellas allow for a little increase in the daylight level in overcast weather conditions by redirecting the daylight from around the zenith sky up to the ceiling and in that way further back into the room.

DESCRIPTION OF THE SHADING SYSTEM

A new solar shading system was developed and tested in full-scale in the Daylight Laboratory at SBi. The system was designed both to fulfil the needs for reducing the energy demand for cooling and ventilation and to allow for a better daylight distribution in buildings.

The solar shading system is set up with horizontal mounted glass lamellas with a highly reflective coating on one side. The lamellas are 50cm wide and the spacing between lamellas is 50cm. The system consists of an aluminium rack with supporting rods for the glass lamellas. The lamellas can be rotated in either direction according to the actual weather condition. In sunny weather conditions, the lamellas are turned into a vertical position with the reflective coating facing the sun. In this way, the system acts as an extra layer of solar control glass that reduces the solar gain while allowing a good view out. The design of the full-scale system tested at SBi is shown in Figure 1 and Figure 2.

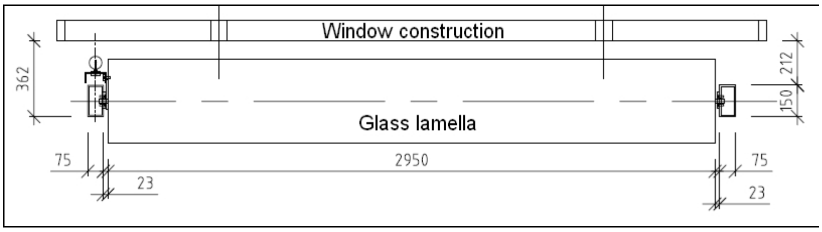


Figure 1. Plane view of the solar shading system.

Modelling the solar shading system using IESve/Radiance (IESve, 2003) for daylight simulations on overcast weather conditions the maximum effect of redirecting the daylight is obtained for a slat angle of 30º. The reflective coating should face the sky. At this angle, the daylight is most effectively reflected on the ceiling and in that way, further back into the room where it is needed (Skotte, 2007). See Figure 3. General dimensions are shown in Figure 1 and Figure 2. The glass lamellas are positioned only 30cm from the facade of the Daylight Laboratory. In real life, the rack and the lamellas would be positioned 50 – 70 cm away from the facade to provide space for maintenance and window cleaning. Figure 3 shows the principle in daylight redirection.

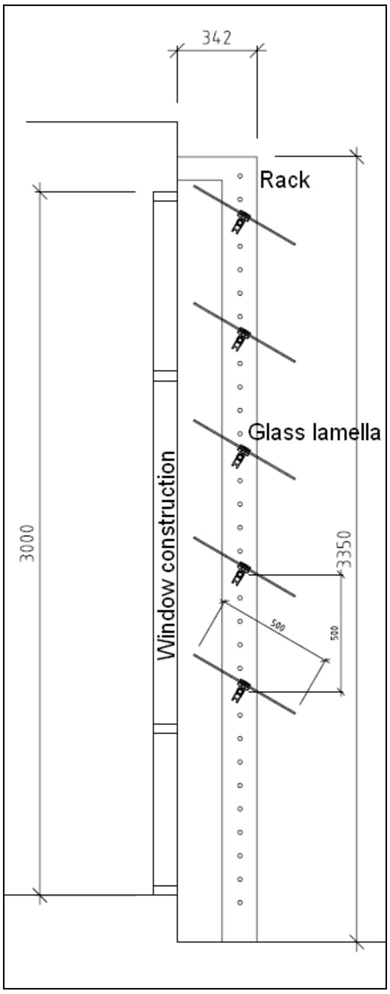


Figure 2. Vertical cross section of the solar shading system

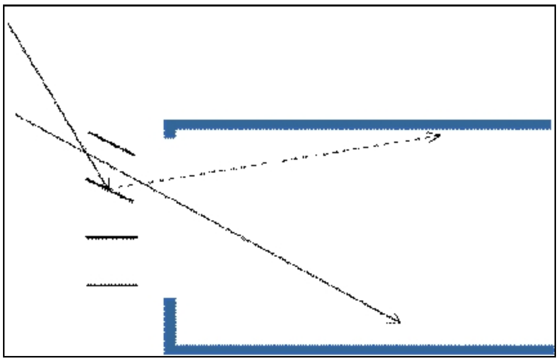


Figure 3. Principle in redirecting the daylight

Scanglas, type Antelio Silver, produce the glass used for the lamellas. This is a solar shading glass with a reflective coating on one side. Data for the glass lamellas are shown in Table 1.

Table 1. Properties of the glass lamellas

Thickness	Solar energy transmittance	Light transmittance	Solar energy reflectance	Light reflectance
8 mm	0.63	0.65	0.25	0.31

MAESUREMENTS

Description of the test facilities

Daylight measurements were carried out on the glass lamella system in Sbi's Daylight Laboratory. The laboratory is situated in Hoersholm, Denmark at 55.86º North and 12.49º East. The Daylight Laboratory has two experimental rooms lying side by side. The floor level of the rooms is 13 m above the ground and the facade is facing 7.5º east of south. The two experimental rooms are of equal dimensions, namely width: 3.5 m, depth: 6.0 m and height: 3.0 m. The test room is where the solar shading system is mounted. The reference room is without any shading system. There is an almost free horizon in front of the laboratory. At a distance, there is a row of trees and a couple of trees in the southwest direction.

Figure 4. At left: glass lamella system in front of test room. At right: reference room.

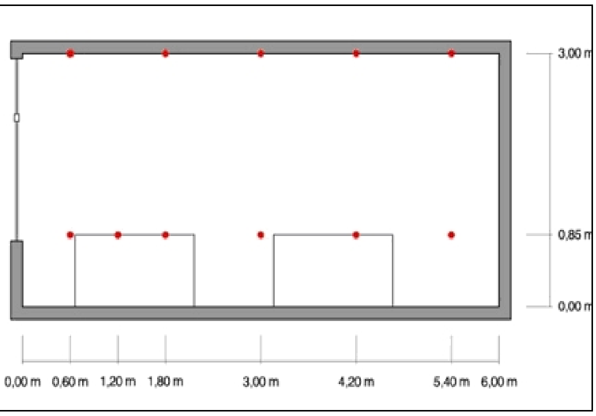


Figure 5. Measurement points in test/reference room shown as red dots.

The facade of both rooms is divided into nine sections. Some of the sections were covered up during the experiments, see Figure 4. Only the middle and upper sections were open to daylight. As can be seen in Figure 1 and Figure 4, the glass lamellas are longer than the width of the glass pane. This makes for an overlap of 0.58 m in each side of the window ensuring that the glass lamellas do cover the whole window area. The glass areas are made of sealed low-e double glazing units with low-emittance coating and argon filling. The U-value is 1.1 W/m^{2}K, the g-value is 0.56 and the light transmittance is 0.72. The two experimental rooms are furnished with two tables each, just as a standard cell office room. The reflectance of the inner surfaces of the rooms are as shown in Table 2.

Table 2. Reflectance of the inner surfaces of the experimental rooms.

Surface	Reflectance
Walls	62%
Ceilings	88%
Floors	11%
Tables	80%

Lux meters are mounted in the longitudinal center axis of both rooms at a height of 0.85 m above the floor (the workplane). Lux meters are also mounted at the ceiling, see Figure 5. The horizontal and vertical illuminance is measured on top of the Daylight Laboratory. Hagner, type MCA-1600 Multi-Channel Amplifier with matching illuminance sensors type SD1, makes the measuring equipment. Illuminance is measured in the unit lux.

Daylight measurements were taken for four different cases. Case 1 and 2 correspond to overcast weather conditions and case 3 and 4 to conditions with sunny sky. In each case, the glass lamellas were set in different positions as illustrated in Figure 6.

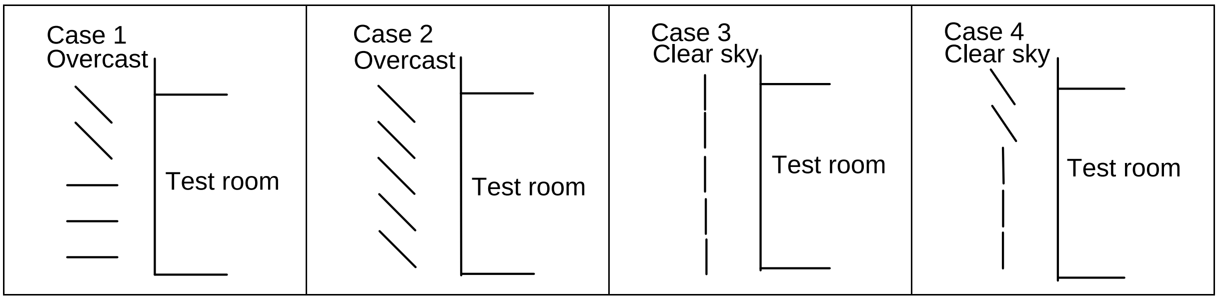


Figure 6. Sky conditions and positions of the glass lamellas in the four cases.

Results of daylight measurements

In the following, the results of the daylight measurements are presented for the four cases. In case 1 and 2 the daylight factor DF is evaluated. The daylight factor DF is defined as the ratio between the illuminance in a point inside the room to the horizontal illuminance outside measured against a free horizon, $DF = E_{inside}/E_{outside}$. E is the illuminance in lux. Evaluation of DF is only carried out for overcast weather conditions. In sunny sky conditions, case 3 and 4, the illuminance measurements themselves are evaluated averaged over a five-minute period.

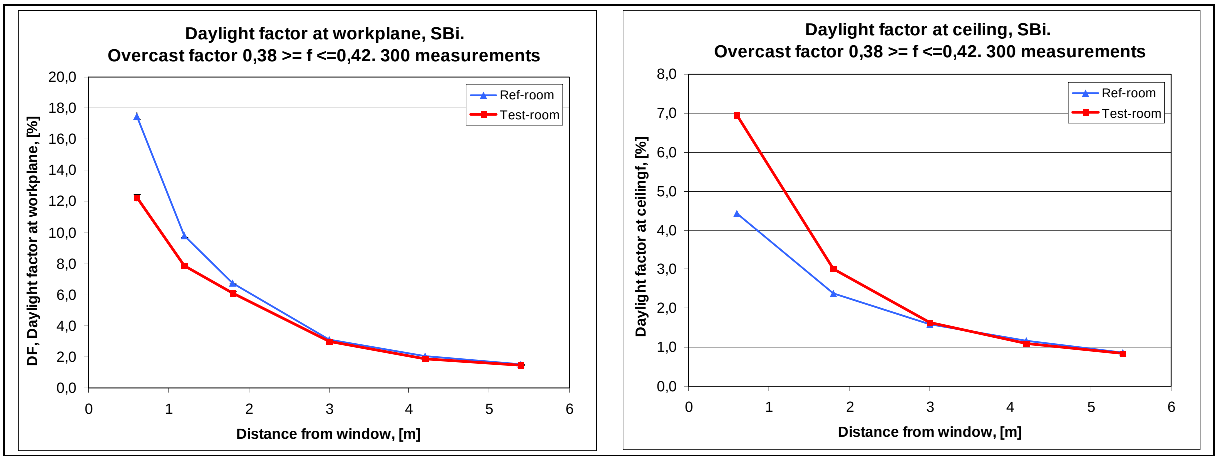


Figure 7. Case 1. Measured daylight factor DF at workplane (left) and at ceiling (right).

Case 1, overcast sky

The results of the measurements are shown in Figure 7. At the workplane 0.85 m above the floor, a reduction of the daylight factor DF is seen throughout the test room in comparison to the reference room. The reduction of DF is greatest near the window area where the illuminance level is abundant already. In the rearmost point of the room, 5.4 m from the facade, DF is equal in both rooms. The tilted position of the two uppermost lamellas and the horizontal position of the three lowermost lamellas yield a small reduction in the total amount of daylight present in the room and an improved distribution of daylight in the room.

At the ceiling, an increase in DF is seen throughout the test room in comparison to the reference room. The increase in DF is most significant in the window area. This indicates that the glass lamellas are mostly reflecting daylight at the ceiling near the window area. Although DF in the test room is decreasing throughout the ceiling, it is higher in the rearmost point compared to the reference room, 0.9 against 0.8.

Case 2, overcast sky

As for case 1 the tilted position of all glass lamellas results in a reduction of the daylight factor DF at the workplane 0.85 m above the floor throughout the test room in comparison to the reference room, see Figure 8. However, the reduction in DF is less pronounced. Again, the reduction in DF on the workplane is greatest in the window area, declining towards the back of the room. However, in the rearmost point of the room, 5.4 m from the facade, DF is greater in the test room than in the reference room, 1.4 against 1.3. In addition, the glass lamellas redirect the daylight resulting in an improved daylight distribution throughout the room.

At the ceiling, an increase in DF is also seen throughout the test room in comparison to the reference room. The increase in DF is most significant in the window area declining towards the back of the room. Again, the DF is a little higher in the rearmost point of the ceiling in the test room compared to the reference room, 0.9 against 0.8.

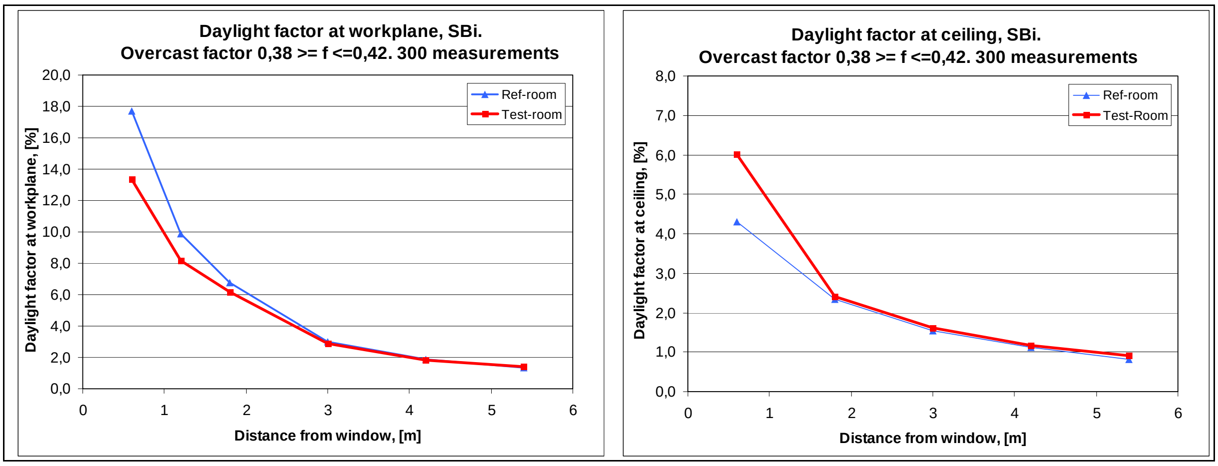


Figure 8. Case 2. Measured daylight factor DF at workplane (left) and at ceiling (right).

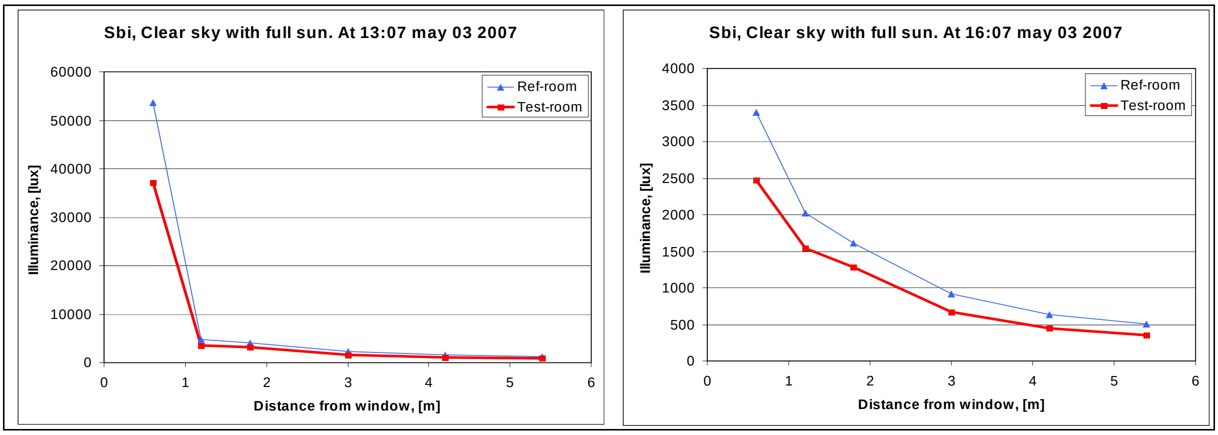


Figure 9. Case 3. Illuminance measured on the workplane at noon and afternoon.

Case 3, sunny sky

In case 3, all lamellas are in a vertical position. The coated side of the glass is facing the sun. In this position, the edges of the lamellas touch each other acting as a new layer of solar control glass in front of the normal facade. The illuminance level is decreased throughout the test room, see Figure 9. The reduction in illuminance level is greatest in the window area and decreases towards the back of the room. At the rearmost point, the illuminance level is still lower in the test room compared to the reference room. The decrease in illuminance level varies throughout the day. This position of the lamellas will be used on sunny days when there is a need for solar shading.

Case 4, sunny sky

In case 4, the two uppermost lamellas are turned into the daylight redirecting position. The three lowermost lamellas are kept in the vertical position. In this case, the effect of using the glass lamella system varies during the day. In the morning, the illuminance level is slightly reduced throughout the room. However, in the afternoon, the illuminance level is only reduced close to the window area, see Figure 10. Further back in the room, the illuminance level is higher in the test room compared to the reference room. This effect has to do with the daylight redirecting position of the two uppermost lamellas reflecting daylight into the room.

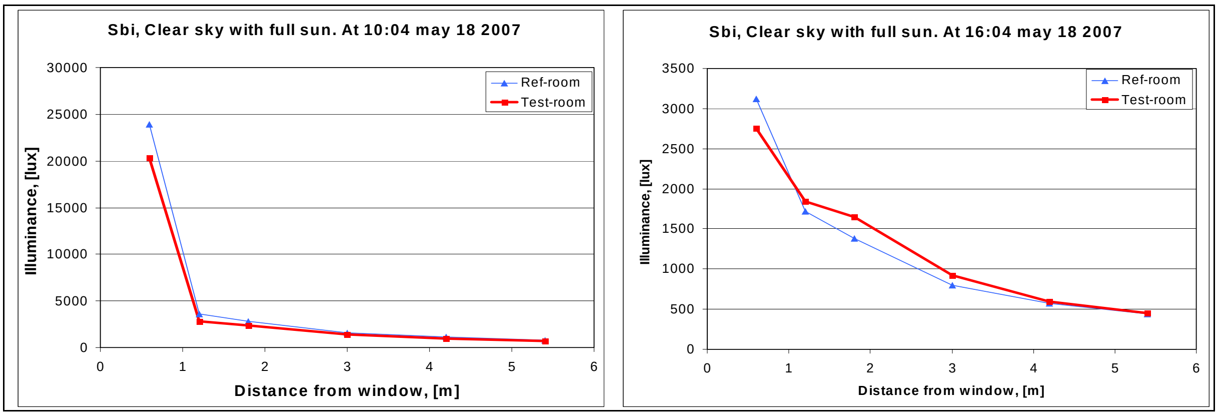
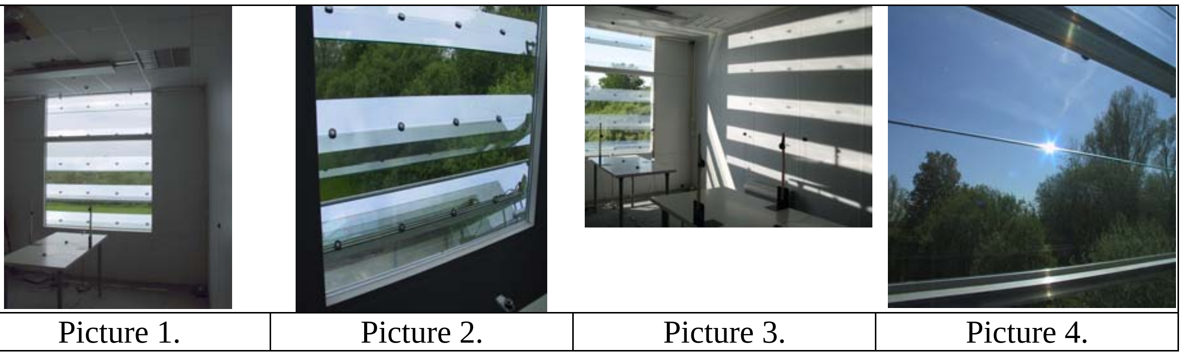


Figure 10. Case 4. Illuminance measured on the workplane at morning and afternoon.

VISUAL COMFORT

Inside the test room, some inconvenient visual effects occurred during the test period. It became obvious that the highly reflective coating on the lamellas could cause glare problems as well as mirroring and discolouring on the walls. These problems were observed both when the lamellas were positioned in the daylight redirecting position and in the vertical position.



Picture 1.	Picture 2.	Picture 3.	Picture 4.

Figure 11. Problems with glare, sky mirroring, disrupted view, sun patches and imaging of the sun was observed.

As seen in Figure 11 picture 1 and 2, glare problems were observed in overcast weather conditions (case 2). The coated surfaces of the lamellas are reflecting daylight up into the ceiling as expected. However, the luminance of the sky is also reflected into the eyes of a user working at the desk. A disruption of the view is also observed. The problems with reflection and mirroring of the sky were most prevalent when weather conditions were about to change for example from overcast to sunny sky. When weather conditions had almost changed from overcast to sunny sky, the lamellas casts very heavy sunny patches on the walls see Figure 11 picture 3. This could be very disturbing to people working in the office, because the patches move over time. If the sky is partly overcast, these patches will come and go which also would be disturbing. In sunny weather conditions, see Figure 11 picture 4, the lamellas are closed in a vertical position. Depending on the viewpoint, an image of the sun would fall on ones eyes. This happens because the image of the sun is reflected in the bevelled edge of the lamellas.

These problems are to some extent related to lamellas mounted below eye level. This indicates that daylight redirecting glass lamellas should only be used in the uppermost part of the facade to avoid problems such as described above. A comprehensive user assessment of the solar shading system is needed to further improve the design.

ENERGY PERFORMANCE

In order to evaluate the impact of the solar shading device on energy consumption in a building, integrated thermal and lighting calculations were carried out using Building Calc/LightCalc (DTU, 2005). The calculations were made on a simple model of a traditional cell office similar to the experimental rooms at SBi. In brief, the results are given in Table 3, (Laustsen et al. 2008).

Table 3. Calculated energy consumption for cooling, lighting, mechanical ventilation and heating in an office building for different solar shading devices.

kWh/m^2 year	Total	Cooling	Lighting	Ventilation	Heating
No shading	76	23	23	26	4
Fixed dark opaque lamellas	72	3	41	21	7
Fixed white opaque lamellas	64	4	31	22	7
Dynamic reflective solar control glass lamellas	60	9	24	23	4

The calculations show that traditional fixed non-transparent lamellas reduce the solar gain more effectively than the tested daylight redirecting solar glass lamellas when it comes to cooling and ventilation. However, the tested system reduces the energy demand for lighting more effectively, resulting in a lower total energy demand. These calculations are preliminary, and must be followed up by more detailed calculations and full-scale energy measurements.

DISCUSSION

The measurements show that the full-scale glass lamella system has performed as expected. In overcast weather conditions the daylight factor DF is reduced in the window area where the daylight level is abundant already. The reduction of DF decreases towards the back of the room. At the rearmost point DF is unchanged or even a little higher when using the lamella system. Consequently, the daylight redirecting lamellas provide a better daylight distribution throughout the room improving visual comfort and reducing the demand for using artificial lighting. In sunny weather conditions, the system is able to reduce the illuminance level throughout the room. This indicates that the solar gain also will be reduced leaving to energy savings for ventilation and cooling.

CONCLUSIONS

A new solar shading system with adjustable glass lamellas was developed. The glass lamellas have a reflective solar control coating on one side. A full-scale prototype of the system was tested at SBi' Daylight Laboratory. In overcast weather conditions measurements show that the shading system improves the daylight distribution throughout the room when the lamellas are rotated 30º outwards with the reflective surface facing the sky. The daylight factor is decreased in the window area. Due to the daylight redirecting properties of the lamellas, the daylight factor DF is unchanged or even higher in the back of the room where daylight is most wanted. On sunny sky conditions, the lamellas are rotated into a vertical position with the reflective surface facing the sun. Measurements show that the illuminance level is reduced throughout the room. This indicates that the solar gain is reduced too. Preliminary calculations showed a possible reduction in energy use for cooling and lighting when using the tested system in comparison to traditional shading systems. Thus, the shading system is able to reduce the total energy demand and at the same time maintain good daylight conditions and view out. Various problems related to visual comfort has been discovered, such as glare, sky mirroring, disrupted view, sun patches and imaging of the sun. When tilted outwards for daylight redirection the reflections from the sky or sun will cause heavy visual discomfort. These problems are mostly related to the high reflectance of the lamellas and especially to those mounted below eye level. This indicates that daylight redirecting glass lamellas should only be used in the uppermost part of the facade to avoid problems such as described above. Preliminary calculations show that traditional fixed non-transparent lamellas reduce the solar gain more effectively than the tested daylight redirecting solar glass lamellas when it comes to cooling and ventilation. However, the tested system reduces the energy demand for lighting more effectively, resulting in a lower total energy demand. The calculations must be followed up by more detailed calculations and full-scale energy measurements. A comprehensive user assessment of the solar shading system is needed to further improve the design and energy efficiency

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