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Laustsen, Jacob B.; Santos, Ines D. P.; Svendsen, Svend; Traberg-Borup, Steen; Johnsen, Kjeld

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Solar Shading System Based on Daylight Directing Glass Lamellas

Jacob B. Laustsen, Assistant Research Professor,
Department of Civil Engineering, Technical University of Denmark;
jbl@byg.dtu.dk

Inês D. P. Santos, Assistant Research Professor,
Department of Civil Engineering, Technical University of Denmark;
isa@byg.dtu.dk

Svend Svendsen, Professor,
Department of Civil Engineering, Technical University of Denmark;
ss@byg.dtu.dk

Steen Traberg-Borup, Senior Researcher,
Danish Building Research Institute;
stb@sbi.dk

Kjeld Johnsen, Senior Researcher,
Danish Building Research Institute;
kjj@sbi.dk

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SUMMARY:
The overheating problems in office buildings must be solved with efficient solar shadings in order to reduce the energy demand for cooling and ventilation. At the same time the solar shading should not reduce the daylight level in the building on overcast days because it would result in a lower visual comfort level and increased energy consumption for lighting.

The paper describes a new type of solar shading system based on dynamic lamellas made of solar control glass with high reflectance coating which reduces the solar gain on sunny days and at the same time is able to redirect some of the daylight further into the back of the room where it is needed on overcast days. Measurements of the daylight performance were carried out on a full scale model of the solar shading system in SBi's Daylight Laboratory. The results show that the shading system under overcast conditions reduces the daylight factor close to the façade while it is unchanged or even higher in the back of the room. Under sunny sky conditions the daylight level is reduced in the office. Compared to traditional solar shading systems with less transparent or opaque lamellas the proposed solar shading system yields a higher daylight factor improving the distribution and exploitation of daylight in the office and furthermore it gives a less obstructed view out. Calculations show that the new system reduces the energy demand for cooling and ventilation when it is used as a traditional solar shading device and furthermore the energy demand for lighting is reduced when the glass lamellas are rotated for redirecting the daylight further into the room.

1. Introduction

The increasing need for energy savings and good daylight conditions in buildings brings about large challenges when designing facades for future buildings since the façade has significant impact on the energy consumption and the utilization of daylight.

A large part of the energy consumption in buildings with glass facades is used for cooling and ventilation to avoid overheating which occurs as a result of the solar gains through the façade. The most efficient way to reduce the cooling demand is by using efficient solar shading devices. The energy demand for electrical lighting represents another large part of the total energy consumption in typical commercial buildings. This can be reduced by optimizing the utilization of the daylight which is also needed in order comply with the requirements of a daylight factor of 2 % on the working place. In buildings with large room depth compared to the window area, the daylight level is normally sufficient or even too high close to the façade but in the back of the room there is often not enough daylight to fulfil the requirements for a satisfactory visual indoor climate.

In many office buildings with glass facades, the solar shading used consists of horizontal fixed lamellas made of opaque materials. These shading systems can reduce the solar gains efficiently but they deteriorate the view out and reduce the daylight level in the building. Thus, there is a need for developing combined systems of flexible solar shading and light directing devices that in addition to reducing the solar gain will ensure a more gradual distribution of the daylight in buildings which will improve the visual indoor climate.

This paper describes a solar shading system based on dynamic glass lamellas with high reflectance. Besides acting as typical solar shading systems reducing the solar gains and consequently the cooling demand, they may at the same time allow better indoor daylight levels than the common shading systems thanks to the transparent properties of glass. During overcast days if they are correctly tilted they may slightly increase the indoor daylight by redirecting the light form the sky up into the ceiling and further into the back of the room.

2. Description of the system

In order to meet the combined needs for reducing the energy demand for cooling by controlling the solar gain and also obtain a better distribution of the daylight in buildings a new solar shading system was developed and a full scale prototype built up.

The solar shading system consists of horizontal glass lamellas with high reflective coating. The lamellas are 50 cm wide and the distance between the lamellas is 50 cm. The large dimensions are chosen to optimize the view out. The lamellas are supported by metal profiles. The lamellas can be rotated in different positions depending on the weather and the requirements for solar shading and improved daylight conditions. On sunny days when the solar gain must be reduced the lamellas are rotated into vertical position acting as an extra layer of solar control glass that reduces the solar energy gain but still allows a good view out. The design of the glass lamella system fitted on a typical glass façade is shown in *FIG. 1* and FIG. 2

Preliminary daylight simulations performed in IESve/Radiance (*IESve(2003))* show that the maximum effect of redirecting the daylight on overcast days is obtained with a slat angle of 30° with the reflective surface upwards. In this position the light from the sky is reflected into the room, up in the ceiling and further back in the room where the light is most needed (Skotte, T. (2007)). See *FIG. 3*. The glass lamellas are positioned 40 – 70 cm from the façade to provide space for maintenance and window cleaning.

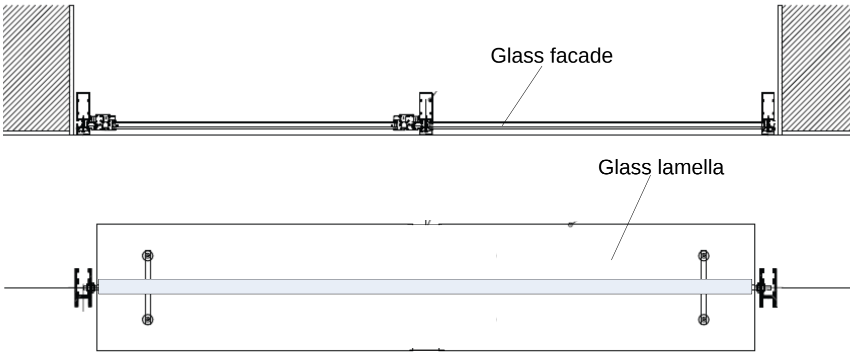

FIG. 1: Horizontal cross section of the shading system.

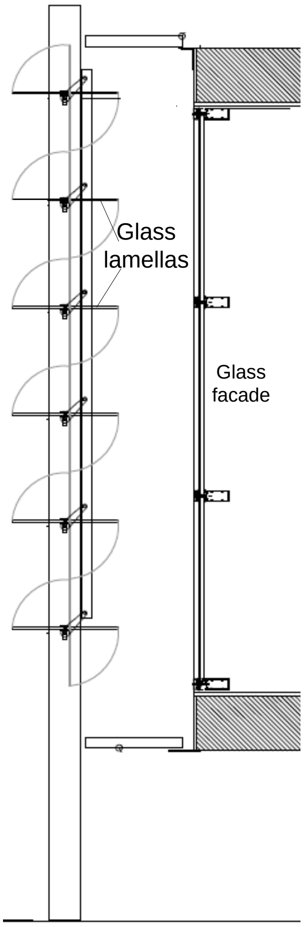

FIG. 2 Vertical cross section of the shading system

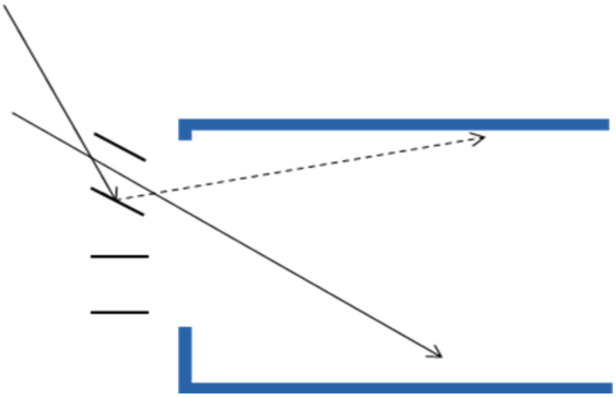

FIG. 3: Principle of the light directing lamellas.

The properties of the solar control glass lamellas are shown in ***Error! Not a valid bookmark self-reference.***.

TABLE. 1: Properties of the glass lamellas.

thickness	Solar energy transmitance	Light transmittance	Solar energy reflectance	Light reflectance
8 mm	0.63	0.65	0.25	0.31

3. Measurements

3.1 Description test facilities

Daylight measurements on the glass lamella system were performed in SBi's Daylight Laboratory situated in Hørsholm (latitude 55.86°N, degree of longitude 12.49°Ø). The daylight lab has two experimental rooms positioned approximately 13 meters above terrain with the façade facing 7.5 degree east of south.

FIG. 4. The Daylight Laboratory at SBi

The interior dimensions of the two experimental rooms are 3.5m wide × 6.0m deep × 3.0m high. The two rooms which are identical are named the test room and the reference room. The space in front of the experimental rooms is a field of grass which is essentially empty from obstructions, apart from the distant row of trees towards south and the group of trees towards the south-west direction.

Both rooms have a glass façade divided in 9 sections. During the measurement some of the sections were blocked so the effective window size was reduced to the middle and upper section corresponding to the size of the glass lamellas. The glass lamellas were mounted outside the facade of the test room, see FIG. 6. The length of the lamellas was 2.95 m. The glazings in the façade of the experimental rooms are sealed low-e double glazing units with low emittance coating and argon filling and U-value of 1.1 1 W/m^{2}K, g-value of 0.56 and a light transmittance of 0.72. The two rooms are designed like traditional cell office rooms but furnished with only two tables. The reflectances of the inner surfaces in the rooms are given in TABLE. 2.

TABLE. 2. Reflectance of the inner surfaces in the experimental rooms in the daylight lab.

Surface	Reflectance
Walls	62%
Ceiling	88%
Floor	11%
Tables	80%

The illuminance values were measured in the experimental rooms with lux meters located in different points of the working plane 0.85 m above the floor and in the ceiling as shown in FIG. 5

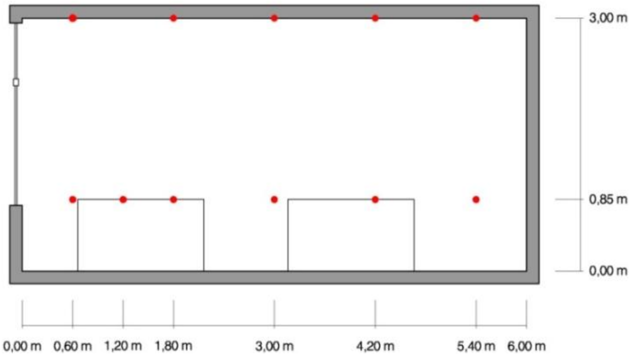

FIG. 5: Cross section of the test room/reference room with location of the measuring points

FIG. 6: Picture of the glass lamella system mounted on the test room façade.

The measurements were performed for four different cases which correspond to different sky conditions and different positions of the glass lamellas as shown in FIG. 7. Case one and two are measured during overcast sky and case three and four are on sunny days with clear sky and direct sun on the façade. For each case measurements of the Test room and Reference room were performed simultaneously so the influence of the lamellas could be assessed.

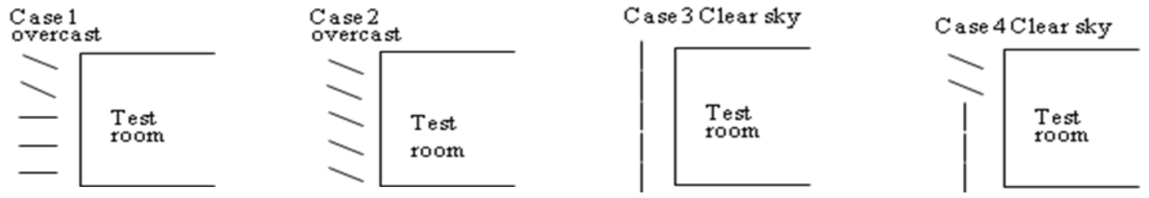

FIG. 7: Sky conditions and position of the glass lamellas in the four cases.

4. Results of daylight measurements

The results of the measurements are presented in the following for cases 1 to 4. Case 1 and 2 are evaluated on basis of the daylight factor which describes the ratio of outside horizontal illuminance under an overcast sky and inside illuminance measured in a specific point. For case 3 and 4 the measurements were performed under sunny sky and therefore the measured illuminances are evaluated directly.

4.1 Case 1, overcast sky

The results of the measurements in case 1 are shown in FIG. 8. It appears that the daylight factor is reduced in the test room with the lamellas compared to the reference room. The reduction is largest close to the facade where the daylight level anyway is abundant and it decreases with the room depth. In the rear most point in the room (5.5m from the facade) where the need for light is highest the daylight factor is equal for both rooms. Thus, the tilted position of the uppermost two lamellas and the horizontal position of the rest of the lamellas result in a small reduction of the total amount of daylight but an improved distribution of the daylight in the room.

The measurements for the ceiling show that the daylight factor increases significant near the façade indicating that the lamellas reflect the daylight up into the ceiling, but the difference decreases gradually in through the room. In the rear most point in the room the daylight factor is highest in the test room (0.9) compared to the reference room (0.8).

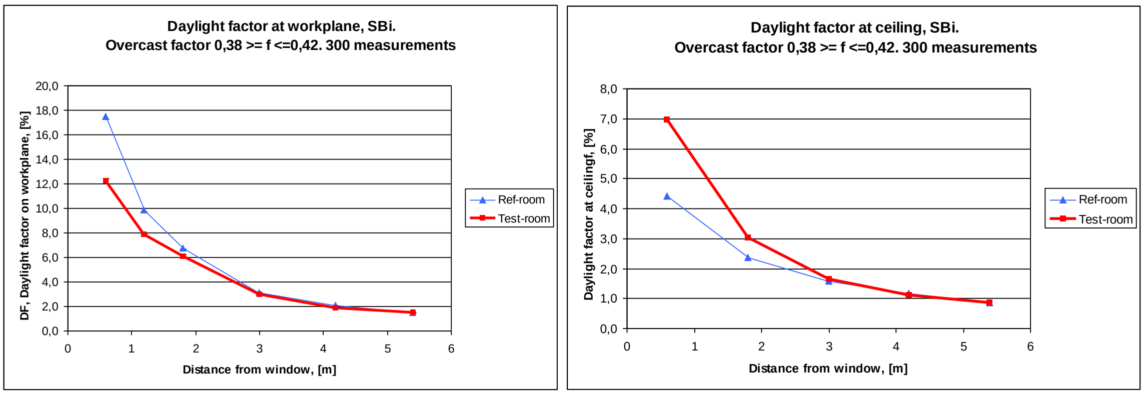

FIG. 8: Case 1. Measured daylight factors for overcast sky. Left : Working plane. Right: Ceiling

4.2 Case 2, overcast sky

The tilted position of all the lamellas in case 2 influences the daylight conditions in the same way as in case 1 as shown in *FIG. 9* but the tendency is less significant. Again the reduction of the daylight factor on the working plane is largest close to the façade and it declines rearwards in the room. This shows that rotating all the glass lamellas 30 degrees towards the façade slightly reduces the daylight factor close to the façade but in the back of the room it is unchanged or actually increased a bit. Hence, the glass lamellas redirect the daylight for the sky resulting in improved daylight distribution and exploitation. The measurements for the ceiling show again that the daylight factor increases significantly near the façade and it is almost unchanged in the back of the room.

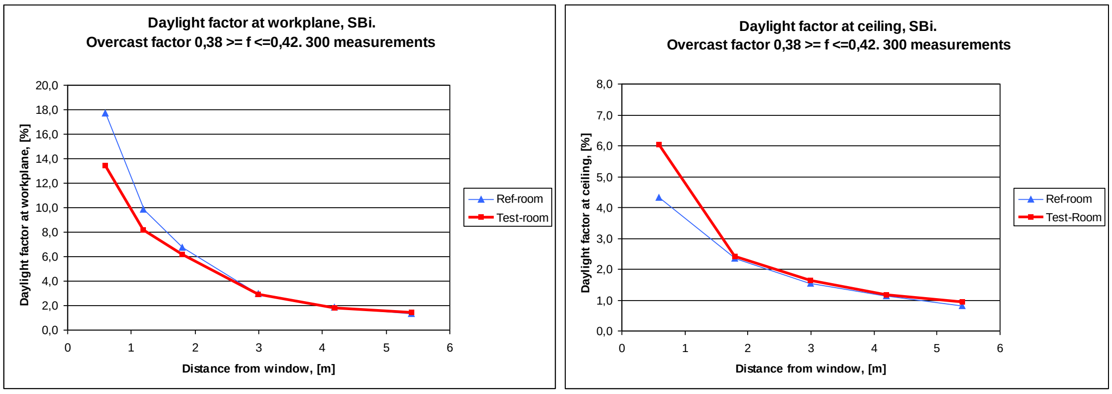

FIG. 9. Case 2. Measured daylight factors for overcast sky. Left: Working plane. Right: Ceiling

4.3 Case 3, Clear sky

In case 3 all the lamellas are in vertical position and because the width of the lamellas and the distance between them are the same they cover the whole façade like an extra layer of solar control glass. The measurements in this case show that the glass lamellas decrease the illuminance levels throughout the room. See

FIG. 10

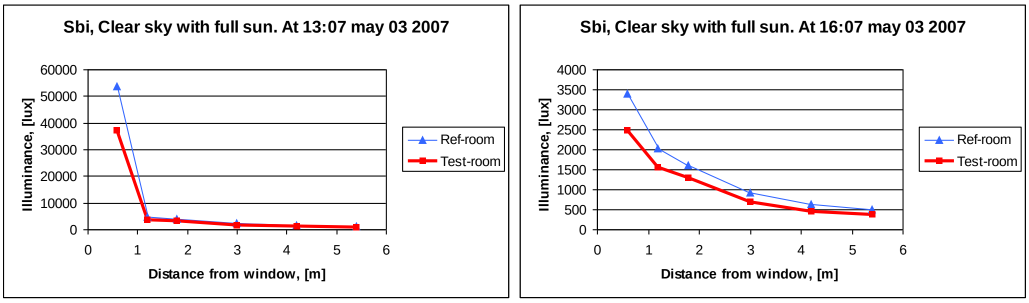

FIG. 10: Case 3. Illuminaces measured on working plane at noon and afternoon.

The reduction is largest close to the window and it decreases gradually with the distance to the window. This position will be used on sunny days when there is a need for solar shading in the traditional way.

4.4 Case 4, clear sky

In case 4 the two upper most lamellas are rotated in light redirecting position and the rest are vertical. The measurements show that the effect of the lamellas in this case depends on the time of day. In the morning the daylight factor is slightly reduced throughout the room but in the afternoon it is only reduced close to the façade. In longer distance from façade the daylight factor is a bit higher in the test room with the lamellas than in the in reference room because of the two rotated lamellas reflecting some extra light into to room.

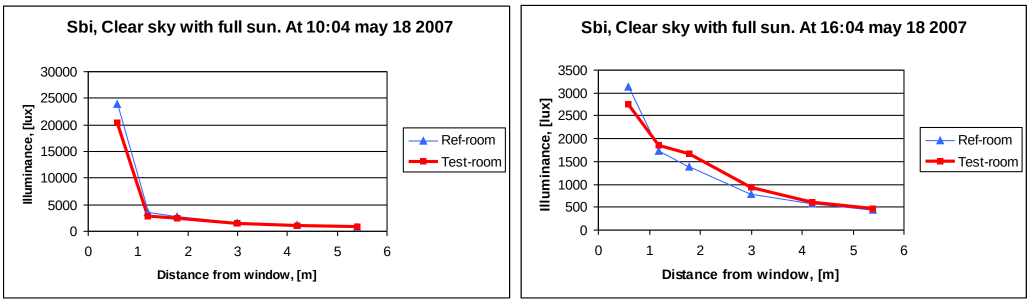

FIG. 11 Case 3. Illuminances measured on working plane at noon and afternoon.

In general the measurements show that the glass lamella system has the expected daylight performance. Compared with the reference room without glass lamellas the daylight factor is under overcast sky reduced close to the façade where the daylight level already is more than sufficient and the reduction is gradually reduced towards the back of the room where the daylight factor is unchanged or even higher with the lamellas. Consequently the light directing glass lamellas provide a better distribution of the daylight in the room resulting in improved visual indoor climate and reduced energy demand for electric lighting compared with traditional non transparent lamella systems. Under sunshine conditions the illuminance level is reduced in the entire room which indicates that the solar gain also will be reduced resulting in energy saving for cooling and ventilation.

4.5 Glare and the effect on the view out

During the measurement period some inconvenient visual effects of the glass lamellas were observed. The high reflectance of the lamellas can cause glare problems when they are rotated upwards in the light directing position. This problem is most significant in direct sun but also in overcast weather the reflected sky luminance can cause vision discomfort. The reflections in the lamellas furthermore reduce the transparency of the lamellas resulting in an obstructed view out as illustrated on

FIG. 12. Therese problems are mainly connected to the lamellas positioned below eye level i.e. 1.8 m above the floor. Therefore the light directing glass lamellas should in some cases only be used in the uppermost part of the façade to avoid glare and obstructed view out. A comprehensive subjective visual evaluation involving the users is needed in the further work of optimizing the design.

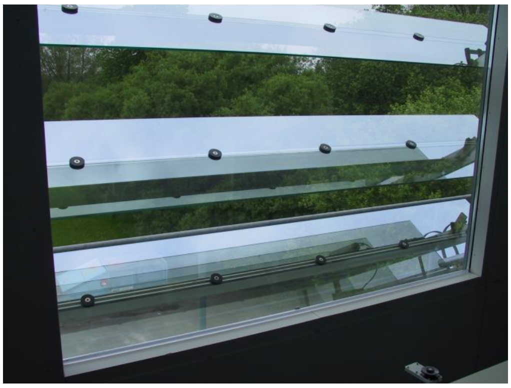

FIG. 12: Reflections in the glass lamellas which can reduce the view out.

5. Calculations

5.1 Energy performance, BuildingCalc

In order to evaluate the impact of the solar shading device on the energy consumption in a building, integrated thermal and lighting simulations were carried out using BuildingCalc/LightCalc (DTU, 2005). The calculations were made on a simple model of a traditional cell office with the dimensions 5m wide × 6.0m deep × 3.0m high with mechanical ventilation and cooling.

The thermal and optical properties of the transparent system consisting of the glazing in the façade in combination with the glass lamellas were determined in WIS (Van Dijk, D., Goulding, J. (1996)). In WIS all the radiation reflected by the shading device is treated as diffuse radiation which is a simplification of reality but it was assessed that the results are reliable. For the same reason WIS cannot handle light redirecting devices correctly which has an impact on the lighting demand. This was compensated for by entering assessed values in LightCalc for the fraction of transmitted light that is redirected (Hviid C. A. et al. (2008)).

The results are given in TABLE. 3

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 efficiently resulting in a lower cooling and ventilation demand than the proposed light directing glass lamellas. On the other hand the glass lamellas reduce the energy demand for lighting resulting in a lower total energy demand. These calculations are only preliminary and must be followed up by more detailed calculations and measurements of the effect of the glass lamella system on the energy demand in a building. Anyway the results indicate that further investigations on the impact of the optical properties of the glass lamellas are needed in order to select a glass type with reflectance and transmittance which will improve the solar shading properties without reducing the daylight properties.

6. Conclusion

A new solar shading system based on flexible glass lamellas with reflective solar control coating was developed and a prototype built up. Daylight measurements in the daylight laboratory at SBi on overcast days showed that the shading device improves the daylight distribution in the building when the glass lamellas are rotated 30° outwards with the reflective surface upwards. The daylight factor is decreased close to the façade and thanks to the daylight redirecting properties of the glass lamellas the daylight factor is unchanged or even higher in the back of the room where daylight is most wanted. Compared to traditional non retractable opaque slat shading devices the new glass lamella system yields a better utilisation of the daylight.

On sunny days, with the lamellas rotated into vertical position, the measurements showed that the illuminance level is reduced throughout the room indicating that also the solar gain is reduced. The impact of the shading system on energy consumption and indoor visual and thermal climate was evaluated in preliminary calculations showing energy savings for both cooling and lighting. Thus, the presented solar shading system is able to reduce the energy demand for cooling and ventilation by controlling the solar gains and still maintaining good daylight conditions and a satisfactory view out. However it is important to take into account the possible glare problems caused by the high reflectance of the glass lamellas. When they are tilted outwards for light redirection the reflections from the sky or sun can be severe resulting in visual discomfort for the users. In some cases the glass lamellas should only be used above 1.8 m from floor level to avoid glare and ensure unobstructed view out.

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