A design method for fixed outside solar shading device

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ABSTRACT: A new sun shading device was developed by Pir 2 architects and the author in conjunction with the design of the "Wonderwall" project. The project was awarded with a purchase in the international architectural competition “The most energy efficient building in Europe” in Bjørvika, Oslo, September 2005. The main reason for awarding the project was the design of the east and west oriented outside walls, equipped with fixed outside solar shading panels. Additionally, fabric curtains were proposed inside the building. The design method described in this paper was developed after the competition. It is based on the idea that solar shading against strong and undesired solar radiation could be separated from solar shading against solar glare. The shading system preventing solar radiation is to be placed outside the façade in form of extremely optimised fixed panels. The outside shading system does not need to be 100% opaque for solar radiation. The shading against solar glare is handled by inside curtains having precisely chosen light transmittance.

Keywords: solar shading, daylighting, sky component, design method

1. INTRODUCTION

To choose or design an optimal sun shading system is not an easy task. Inside systems are cheap, but they do not prevent overheating. Most products reflect only about 1/10 of solar heat outside; the rest is accumulated inside the building. If controlled manually, most people close them as soon as the sunlight is annoying and forget to open them when sunlight disappears. It results that they are in the closed position not only during sun hours, but also during most part of overcast sky hours, i.e. when daylight is really needed.

Outside systems prevent overheating very well, but they have to be very robust and to be mechanically controlled. Therefore most products in this category are very expensive. Also many types of sophisticated motorized sun shading devices for outside usage are on the marked today, there is still a need for development of fixed sun shading devices, e.g. for low-cost buildings having overheating problems where the motorized devices are too expensive or where fixed devices are preferred because of extreme weather conditions

2. CLIMATE AND LOCAL CULTURAL CONDITIONS

High latitudes are characterized by low mean solar altitude angle, by sunlight having low luminous intensity and low colour temperature in a large part of the year. The sky is overcast in nearly half part of the day hours during a year. In windy regions the changes in cloud cover are very fast; the shading control systems fail to handle them properly.

Since the sunshine is a seldom guest in Northern countries, especially during winter, most people living there appreciate sunlight very much. People love to experience solar heat on the body and they admire sun patterns both, on interior and exterior surfaces.

They learned to avoid glare form a low sun by changing the view direction and/or changing the position of visual task. In situations were this is difficult, people have traditionally used diffusing indoor curtains to cover part of the window(s).

Curtains are generally welcomed because they partly reduce acoustic problems as well and give the interior designer opportunity to add nice colours and patterns to the interior in a cheap and flexible way. Curtains lighted by sunlight are often very nice visual elements with luminance and colour gradients that are difficult to obtain with other methods.

3. METHOD

3.1 Window design

The method starts with the design of a window in accordance to the architectural idea for the building and the function of the room where the typical issues as view out and view in, privacy-transparency should be considered. Daylight factor should be calculated using one of the simple design tools to ensure that DF is higher than the recommended one for the room or the task, DF > DF_{min}.

3.2 Sky sector for undesired solar radiation

The intensity of solar radiation depends very much on the altitude angle of the sun. In Scandinavian countries the solar radiation intensity is highest for altitude angle around 30°, on the other side a radiation from altitude angles lower than 15° will usually not contribute to overheating in typical rooms.

The second aspect is the variation of transmission of solar radiation through a glass pane with incident
angle. For very large incident angles (e.g. slant angles lower than 15°) the transmission of solar radiation is negligibly low.

The third aspect is the occupation schedule of the building. For example, for an office building the internal heat load due to office equipment, electrical light and people starts at about 8:00-8:30. During the first hour the internal heat usually do not causes overheating, so the reasonable start point for overheating problems is 9:00, see figure 1.

Find the mean solar azimuth angle ($\alpha$) and altitude angle ($\beta$) for the HSS; in our example the angles are: $\alpha = (45+15)/2=30$, $\beta = (47+15)/2=31$.

To shade the window at the time point when the azimuth angle of the sun is exactly equal to the mean azimuth angle of HSS, the shading panel should cover the space between lines $k$ and $l$, figure 2. The panel itself can be perpendicular to the façade or, to minimize its area, perpendicular to the sunray direction ($k$ and $l$). It can be situated closely to the window or not. By moving the panel away from the window the view out increases, but the possibilities to shade against sunrays from other directions decreases.

How far away from the window can the shading panel be situated to ensure minimum 50% shading at the borders of the HSS?

To answer this question the altitude and the azimuth angles for borders of the HSS are to be found: in our example:

\[15 < \alpha < 45 \quad \text{and} \quad 15 < \beta < 47\]

The optimal position of the panel in plan is shown in figure 3 and in vertical section in the sun direction in figure 4. If the demand to shading degree is stronger, e.g. 100%, the shading panel has to be enlarged as illustrated by the detached lines on figures 3 and 4.

Figure 1: East + 20°N oriented glass pane, the sun diagram for Trondheim and a Heat Sky Sector.

Figure 2: Sections: horizontal and vertical in the sun direction through a window, alternative forms and positions of shading.

Figure 3: Optimal shape and position of the shading panel, horizontal section.

Figure 4: Optimal shape and position of the shading panel, vertical section through the window in the sun direction.
The graphical analysis shown in figures 3 and 4 should give designers enough information to make an initial design of the shading panel.

3.4 Obstruction of the diffuse light.

At this stage the designer can be sure that the room behind the window will not be overheated due to strong solar radiation, but since the panel is fixed, it will obstruct diffuse light in overcast time periods, too. To analyse the obstruction of diffuse light from the overcast sky the CIE standard overcast sky with precisely defined luminance distribution can be used; it is shown for 10º horizontal sectors in figure 5 (left).

The transmission pattern of the glazing that depends very much on incidence angle, figure 5 (right) has to be considered as well.

The combination of those two variables causes that the contribution from unit (10º x 10º) sky sectors to SF in the room at the middle of the window varies considerably. The SF contribution from the respective unit sectors was calculated and rounded to 0,1; the middle values for respective sky units are presented in table 1 and figure 6.

Table 1: SF contribution from the 10º x 10º sky sectors corrected for transmission through a two glass panes.

<table>
<thead>
<tr>
<th>VERT shad. angle</th>
<th>HORIZONTAL shading angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-10</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
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<td>0,15 0,15 0,15 0,15 0 0 0 0 0 0</td>
</tr>
<tr>
<td>20-30</td>
<td>0,25 0,25 0,25 0,15 0,15 0 0 0 0 0</td>
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<tr>
<td>30-40</td>
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</tr>
<tr>
<td>40-50</td>
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</tr>
<tr>
<td>50-60</td>
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<td>60-70</td>
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<tr>
<td>70-80</td>
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</tr>
<tr>
<td>80-90</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

In figure 6 the precise values are presented for a sky unit sectors in vertical section perpendicular to the window surface.

The SF sky-unit diagram in figure 7 is a new form for graphical presentation of SF contribution, similar to the vertical sky component overlay published by Tregenza and Loe [5] for stereographic drawing or to the pepper-pot diagrams published in 60-ties by Pilkington Brothers [4] and Lynes [1].

The proposed diagram should be even more useful for architects because it is constructed by equidistant representation of vertical and horizontal lines seen from a given point on the horizontal plane. It is easy to find a vertical and a horizontal shading angle on it, see figure 8. It should be also easier to draw a typical orthogonal geometry of outside shading elements on it. It is somewhat analogous to the obstruction mask protractor based on equidistant projection published by Moore [3]. The vertical lines are projected as radius lines, the horizontal lines as boat-like lines.

The sky-unit diagram takes into account the light transmission of a standard glass. For other types of glass a correction factor should be used. The total SF contribution from the unobstructed sky visible from the vertical window is about 26%. 

Figure 5: A vertical section through a window; the luminance distribution of the standard CIE overcast sky as the percentage of zenith luminance for 10º sky sectors to the left and angle dependent light transmittance 2 glass panes, 10º sectors, to the right.

Figure 6: Vertical/orthogonal section through a window and SF contribution through a two pains of glass from the 10º x 10º sky unit sectors.

Figure 7: SF sky-unit diagram. Grey gradients refer to the table 1.
3.5 Correction of the initial design.
To find out how much of diffuse light the shading panel obstructs, a geometrical representation of the shading panel, an obstruction mask, has to be drawn at the SF unit diagram, figure 9. We assume that the shading element is made of vertical and horizontal elements parallel to the façade wall. The first step is to find the vertical shading angle referring to the altitude angle for the sunray representing the middle point of the HSS, see figure 8. It can be fined graphically at the intersection of a 31º ring and the 30º azimuth line in figure 9. On the bout-like pattern we find that in our example the vertical shading angle is about 50º. Alternatively, the vertical shading angle can be calculated using the formula [7]:

\[ \text{VSA} = \arctan\left(\frac{\tan(\text{ALT})}{\cos(\text{HSA})}\right). \]

where:
- ALT-altitude angle
- VSA-vertical shading angle
- HAS-horizontal shading angle

The same approach should be repeated for the lower and the upper border of the shading panel. The hatched area in figure 9 refers to the boundary angles of Heat Sky Sector in our example. If the panel has e.g. a vertical form, a much larger area between 15º and 45º azimuth lines should be hatched.

A simple count of amount of shaded sky units multiplied by the contribution they give indicates that the shading panel from our example will reduce the SF from the maximum value of 26%, to about 23.7%, i.e. by about 9%. To simplify the analysis, let us assume that the daylight factor will be reduced proportionally to the SF. The DF calculated at the first stage should be reduced consequently by minimum 9% and compared to the DF_{min}. If the corrected DF is too low, the shading panel design should be optimised (if possible) or the glazing area of the window should be increased accordingly.

If there are other outside obstructions than shading panels, e.g. terrain or neighbouring buildings, they could be shown on the diagram and taken into evaluation as well.

3.6 Inside shading
The choice of inside curtains is usually a part of interior design and not always architects are involved in the process of a curtain material choice. Most curtain textiles diffuse sunlight. Textiles having high total transmittance can actually increase the glare, because the window surface covered by them can have very high luminance. To reduce the window luminance a lower transmittance is preferable. In rooms with VD units the total transmittance of glazing and curtain together should be definitely lower than 10% [6].

4. WONDERWALL
The shading concept for the Wonderwall project was limited to the east and west oriented facades and was based on following principles.
Windows were divided horizontally into the small upper part and a much larger lower part. The upper part is “always transmitting” for the sun and skylight with no any internal shading. The efficiency of the upper part is additionally increased by an outside and inside light shelf. Additionally, it functions as an extra intake of fresh air, see figure 11.
The lower part gives view out and is equipped with internal curtains against solar glare. It is also shadowed with outside fixed panels against overheating. The outside panels are sloped in two directions, see the axonometric perspective in figure 10; the surface of the panels is oriented perpendicularly to the direction of the sunray from the middle of the HSS. The sloping angles of the panels were calculated very precisely.

Since the windows are arranged in a window belt, the panels are arranged in a pattern of parallel, sloped elements creating a form for outside shelter, a wonderwall. The wonderwall is situated about 60 cm from the façade and makes a transparent but precise covering of the facade. To enable sunlight penetration through the upper windows and not interrupt the continuity of the wall, the panels are turned in the direction parallel to the sunrays at the height of upper windows and parapets, figure 12 and 13.

5. DISCUSSION

The shading effect of any outside shading element will vary inside the room. Only in points that see the shading element the reduction of sky factor can be considerable. In points that do not see the element, SF will not be reduced at all. To make more precise calculations, the point(s) of special interest in the room should be chosen instead of the middle point of the window. In projects where precision is not to be very high the middle point at the window is a good choice, the effect of shading element will be even larger than for many points inside the room, in this way the method gives a good guarantee, that DF will not be reduced too much.

In the preliminary stage of an architectural design process or in situations where the high accuracy is not necessary, the SF sky-unit diagram can be used to calculate sky factor in some interesting points in the building. Very often the daylight factor calculations can be stopped when the calculated SF is higher than the minimum recommended daylight factor level.

The fixed shading panels are intended to be used mostly on the east or west oriented facades, where the overheating risk is limited to few hours and where the shading panels can be oriented as an umbrella in direction toward the most undesired sunlight direction. At a south oriented facade the overheating risk occurs much longer and a shading panel could reduce the diffuse light too much.

6. CONCLUSION

The method presented in this paper can help architects to design outside shading elements and evaluate their impact on reduction of SF from overcast sky graphically in an easy and secure way. The method can be used also for other types of outside obstructions. The SF sky-unit diagram can be used in simplified SF calculations in buildings.
ACKNOWLEDGEMENT

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REFERENCES