EVALUATION OF
OVERHEATING PROTECTION WITH
SUN-SHADING SYSTEMS

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Abstract – Sun-shading systems have to provide thermal and visual comfort reliably and economically. At the same time, they should prevent unwanted solar gains in summer and permit high solar gains in winter. This paper describes a method for the assessment of the heat barrier effect of different types of sun-shading systems together with the associated control strategy. The starting point for the performance assessment is adequate characterization, appropriate to the size and complexity of the facade of the assessed building. The thermal characterization consists of the angle-dependent determination of the Total Solar Energy Transmittance $g$ with a calculation method, which is validated with calorimetric measurements. The combination with typical irradiance distributions allows the evaluation of different control strategies. This paper shows that it is essential for the reliability of the calculated cooling and heating loads, that this calculation is based on a control strategy, that fits with the priorities of the building users.

1. INTRODUCTION

Optimal use of daylight and solar heat gains in buildings is made possible by the use of good sun-shading systems. This means that sun-shading systems must be able to control and regulate solar gains through facades. At present, there are no reliable standard methods for the evaluation of the effectiveness of sun-shading systems. This means that architects and building designers have to make their own decision on the methodology. Frequently, this decision is wrong, as we know from buildings with overheating problems in summer. In some of these cases, the Fraunhofer ISE made studies in order to detect the error. The most frequent problem in our experience is that people do not want to use the shading systems in the way they are planned to be used. One example: In many cases building designers assume that people are willing to close the slats of venetian blinds in summer, which is not true in most cases. The demands of the future users of the building have to be taken into account in an early stage of the planning process! The effectiveness of a sun-shading system has to be assessed with methods that are able to take the various demands into account. This means that the planning team of a building has to agree on a control strategy that fits with the priorities of the future users.

We developed a methodology to assess the effectiveness of a sun-shading system together with the associated control strategy. The methodology has been validated with internal and external venetian blinds supplied by the company Hüppe Form, Oldenburg, Germany. The next section is a discussion of the requirements of users. A presentation of the methodology then follows.

2. USER REQUIREMENTS

Figure 1: User requirements

Figure 1 gives an overview of the requirements for sun-shading systems. The most important factors for the behaviour of users are the thermal and daylighting requirements.

Figure 2 specifies thermal and optical requirements in detail. It should be recognized that it is impossible to optimize all criteria simultaneously. It is always necessary to find the compromise that best matches the
priorities of the user. Three examples shall demonstrate this:

1. For many systems, good visual contact to the exterior is only possible with reduced heat protection.
2. In many cases, a sufficient supply of daylight is only possible with reduced heat protection.
3. The winter solar gains are reduced, when shading systems are used for glare protection.

requirements and high thermal comfort

3. g-VALUE AS A MEASURE FOR SOLAR GAINS

3.1 The meaning of g
To assess the heat barrier effect of shading systems, a characteristic number is needed which quantifies the solar thermal gains through facades: The total solar energy transmittance $g$. The $g$ value specifies the total fraction of incident solar energy which is transmitted through a building component. The transmitted energy fraction consists of two parts: The solar transmittance and the secondary internal heat transfer factor $q_i$.

• The position of the blind (internal, integrated or external).
• $g$ depends on the glazing and the blind. In particular the effectiveness of internal blinds is higher, if they are mounted behind a solar control glazing, instead of a glazing with the heat mirror on the outer surface of the inner pane (heat mirror glazing). The reason is that in the first case, the reflected radiation from the blind is mainly absorbed in the outer pane. In the second case it is mainly absorbed in the inner pane.
• The wind conditions.
• The ventilation of the gaps.
• The direction of the incident irradiation.

Especially the last point is commonly neglected or not treated correctly during cooling load calculations. It is important to note that the $g$ value can be higher for oblique angles of incidence. This is very often the case with blinds made of slats that can be tilted and control strategies with variable tilt angles of the slats. This means that the angular dependence of $g$ must be taken into account.

3.2 Methods for the determination of g
There are two fundamentally different methods to determine $g$:

• direct calorimetric measurement
  In this procedure a segment of the real facade (e.g. 1m² glazing plus blind without the frame and surrounding support structure) is measured directly. This is done by irradiating the sample either with sunlight or a solar simulator. Behind the facade, the transmitted energy is determined calorimetrically.
  For a detailed discussion see [Platzer et. al. 1997] or [Platzer 2000].

• calculation methods
  The starting point of this method is the determination of the optical properties of the different layers of the facade (e.g. transmittance, reflectance and absorptance of a venetian blind with a defined tilt angle of the slats). These fundamental properties can be determined by optical measurements or with additional calculations by which the overall properties of the layers are calculated from the material properties.
  The second step is the calculation of the solar direct-hemispherical transmittance $\tau_e$ of the whole system and the absorptance in each of the layers.
  The last step is the calculation of $q_i$, the inward flowing fraction of the overall absorbed energy. The sum of $\tau_e$ and $q_i$ equals $g$. 

Figure 3 illustrates the meaning of $g$ for the example of an internal roller blind. In this case, a $g$ value of 0.3 means that 30% of the incident radiation is transmitted into the building. The following factors influence the effectiveness of blinds and shutters, the exact value of $g$ depends on these boundary conditions:
Comparative discussion of the two methods:

Advantages of the calorimetric measurement:
- Direct measurement without model assumptions. This means that it is a reliable method.
- No modeling necessary. This means, that this method is quicker for complex configurations.
- Since real samples are assessed, deviations from the ideal properties of the samples are included in the result (e.g. unequally tilted slats).

Disadvantages of the calorimetric measurement:
- Many time-consuming measurements are required to cover all the required combinations of glazing and blind with the defined operation modes and angles of incidence.
- A sample of the facade has to be constructed and sent to the laboratory.

Advantages of the calculation methods:
- When the model has been prepared, the effect of modifications can be assessed quickly and easily. (e.g. different tilt angle or color of the slats)
- No samples of the whole facade segment are required

Disadvantages of the calculation methods:
- Validation with calorimetric measurement is mandatory.
- At present there are no standards or draft standards which consider the angular dependence of g.

3.3 Description of the chosen method
The Fraunhofer Institute for Solar Energy Systems ISE compared different calculation methods with calorimetric measurements for the company Hüppe Form, Germany. Together with the R+D department of this company, we have chosen a practical method that is accurate, but not too costly. In this calculation method, the characterization of the optical properties of the venetian blinds is done with ray-tracing methods. The physical mechanisms considered during the ray-tracing process are shown in figure 4.

The results of the ray-tracing process are the optical properties (reflectance, absorptance and transmittance) of a venetian blind for variable tilt angles of the slats and variable directions of the incident irradiation. The basis of the method is a geometrical model of the blind, which describes the form of the slats, the distance between the slats and possibly existing perforated regions of the slats. The optical properties of the individual slats are determined in a measurement. The next step is a computer simulation of an optical measurement, which means that many virtual light particles (photons) are incident on the blind with a defined direction. The evaluation of this virtual experiment is to count the reflected and the transmitted photons. The ratio of the reflected or transmitted photons to the incident photons is the reflectance or transmittance respectively.

3.4 Validation of the method
The accuracy of the method has been assessed for two different internal venetian blinds and one external venetian blind. The following systems were provided to us by the manufacturer Hüppe Form, Oldenburg, Germany:
- External venetian blind with metallic light grey slats. The width of the slats is 80 mm, the vertical distance between the slats 72 mm. The slats are rollformed and convex (edges curved downwards). A schematic drawing of the slats is shown in figure 4.
- Internal venetian blind with white slats. The width of the slats is 25 mm, the vertical distance between the slats is 20 mm. The slats are convex and perforated, except for an 8 mm broad area in the middle of each slat. »Perforated« means that there are many small holes in the slat. The transmittance of the perforated area was 7.7%.
- Internal »daylighting« venetian blind. The slats are concave (edges curved upwards), the upper side is coated with a mirror foil, the lower side is painted matt light gray. The width of the slats is 25 mm, the vertical distance between the slats 20 mm. The slats are convex and perforated, except for an 8 mm broad area in the middle of each slat. The transmittance of the perforated area was 7.7%.

Figure 4: Schematic drawing of the mechanisms, considered in the ray-tracing method
For the validation measurements, the blinds were combined with a heat-mirror glazing manufactured by Pilkington. The product name of the glazing is K-Plus S. The comparison between measured and calculated g values is shown in table 1-3. For the case of the internal white venetian blind, one can see the excellent agreement between measured and calculated values (table 1).

For the »daylight« venetian blind, we found in principle the same very good agreement. There are two exceptions: The first and the fourth measurement. In the first case the measurement is difficult, because of the strong dependence of g on the tilt angle of the slats. (In this case the slats are closed 8° more than cut-off 1). In the fourth case we assume that the blind was not always closed exactly in the same way.

The calculated results for the external venetian blinds are always slightly higher than the measured values. Concerning the heat barrier effect, the calculated values are on the safe side. The absolute difference (around 0.3) is sufficiently small.

The results of this section can be summarized with the following statements: The results of the calculation method have been validated with three very different types of blinds and different combinations of altitude and azimuth angle. For these validation measurements, the blinds have been combined with a heat protection glazing. The agreement between modeled and calorimetrically measured values is very good.

4. MODELING OF THE SKY RADIANCE

The angle-dependent g value is not sufficient for the evaluation of the heat barrier effect of sun-shading systems for two reasons: Most of the control strategies for venetian blinds use variable tilt angles of the slats with the tilt angle depending on the actual position of the sun. In addition, the angular distribution of the irradiation has to be considered. This means, that it is necessary to take into account typical weather and irradiation data for the location of the building. In our calculations this was done on the basis of hourly direct horizontal and diffuse horizontal irradiance data taken from the respective Test Reference Year (TRY) [Blümel et al., 1986]. The sky radiance distribution was calculated using the Perez model [Perez et al., 1990], [Perez et al., 1993]. The continuous radiance distribution of the diffuse sky was discretized by splitting it into 145 circular angular patches with cone openings of 11.15° according to Tregenza [Tregenza, 1987]. The ground was assumed to be an isotropic diffuse reflector with an albedo of 0.2. The ground surface was divided into 90 discrete patches. Direct irradiation was treated as a parallel beam. The direction of the beam was calculated from the geogra-

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1 The slat position »Cut-Off« depends on the direction of the irradiance. In this position the slats are open as wide as possible without letting the sun shining directly through the blind.
phical position, date and time. For the calculation of this radiance distribution a modified version of the program gendaylight has been used [Reinhart et al. 2000].

5. ASSESSMENT OF THE HEAT BARRIER FUNCTIONALITY OF BLINDS TOGETHER WITH THE ASSOCIATED CONTROL STRATEGY

5.1 Control strategies
In the following, we demonstrate the new methodology for the case of an external venetian blind with white slats in combination with heat protection glazing (Interpane iplus neutral R, $U_{DGU} = 1.2 \text{ W/m}^2\text{K}$, $g_{DGU} = 0.60$). The slat width and slat geometry of the venetian blind is shown in figure 4. The starting point of the performance assessment is the decision about the control strategy. As stated above, this decision should be made together with the client and – if possible - the future user. This means that we are not able to define a general control strategy as a basis of the assessment. Instead of trying to do this, we want to assess the performance of the system for two very different control strategies.

1. Strategy »closed«
   With this strategy, the slats are always closed totally, when the facade is irradiated directly by the sun. The blind is fully retracted, when the facade is in the shade or when there is no direct illumination. For a given combination of blind and glazing, this control strategy maximizes the overheating protection and glare protection when the sun hits the facade directly. This control strategy ignores the need for visual contact to the exterior. The dimensions of the room and the windows will determine whether the supply of daylight is sufficient or not. According to our experience, this strategy can be used very often as a worst case for the planning process. This does not imply at all that an automatic adjustment of the slats is necessary. The user is free to close the slats more than cut-off, but overheating protection is not guaranteed, if the slats are opened further than cut-off. For the cut-off strategy, the tilt angle of venetian blinds is determined by the profile angle of the sun. The profile angle is the projection of the solar altitude angle on a vertical plane perpendicular to the surface of the facade.

2. Strategy »cut-off«
   As for the first strategy, the blind is fully retracted, when the facade is in the shade or when there is no direct illumination. When the sun is shining directly on the facade, the slats are tilted into the cut-off-position. The slat position »cut-off« depends on the actual position of the sun. In this position, the slats are opened as far as possible without letting the sun shine directly through the blind. This control strategy eliminates glare caused by direct irradiation from the sun and it ensures some kind of minimum overheating protection. An Advantage is the visible contact to the exterior because of the opened slats, at least for higher positions of the sun. Because of the protection of the room from direct irradiation, the strategy ensures, that there are no directly lit stripes on desks or workbenches. This means, that it eliminates very uneven illumination of the room. The dimensions of the room and the windows will determine whether the supply of daylight is sufficient or not.

5.2 Angle-dependent g values
The following figures 6-8 show the angle dependent g value for the example under consideration. The g value is shown in local coordinates, which means that the coordinate system is fixed with respect to the surface of the facade. When the facade is vertical and south oriented, the local and global coordinate systems are equal. In this case local and solar azimuth angles and local and solar altitude angles are identical. The local coordinate system was chosen because it is independent of the orientation of the facade.

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2 There is no guarantee that this control strategy actually ensures sufficient glare or overheating protection!
5.3 Solar gains and effective g-values

Knowing the angle-dependent $g$ value and the radiance distribution of the incident irradiation, we calculated for every hour of the year the incident solar energy and the energy transmitted into the building. We did this for south, east and north oriented facades. The ratio of the monthly sum of the transmitted to the incident solar energy is the effective $g$ value $g_{\text{eff, orientation}}$ for this month.

$$g_{\text{eff, orientation}} = \frac{\text{monthly sum of solar gains}}{\text{monthly sum of incident irradiance}}$$

In this effective $g$-value are all different operation modes of the sun shading system included. In particular, the time is included, when the system is retracted because of being in the shade or because of purely diffuse irradiation. For the evaluation of the performance it is important to know the behavior of the system, when it is not retracted. Because of this, a second effective $g$ value was defined that takes into account only the time when the system is active:

$$g_{\text{eff, sunshading active}} = \frac{\text{monthly sum of solar gains, if system active}}{\text{monthly sum of incident irradiance, if system active}}$$

The following figures show the solar thermal behavior of the example under consideration. First we evaluate the control strategy »cut-off«, then we assess the control strategy »closed«.

In the following figures, the effective $g$ values are plotted with lines. Figures 10 and 12 show the effective $g$ values and the associated solar gains for the whole months, including the time when the venetian blind is retracted. The only difference between figure 10 and 12 is that figure 10 is valid for the control strategy »cut-off« and figure 12 for the strategy »closed«. Figures 11 and 13 show the effective monthly $g$ values for the time, when the sun-shading system is active. This means that all ours with purely diffuse irradiation or with the facade being in the shade are not considered in $g_{\text{eff, sunshading active}}$. The only difference between figure 11 and 13 is the control strategy for the blind.

Figure 9: Tilt angle of the external white venetian blind depending on the profile angle. The control strategy is cut-off.
TRY5 (Würzburg), External white venetian blind + heat-mirror glazing

Figure 10: Solar gains and effective $g$ values for a vertical facade in Würzburg, Germany (TRY5). The facade consists of the external white venetian blind in combination with the heat-mirror glazing. The control strategy is »cut-off«.

External venetian blind + heat-mirror glazing. TRY5

Figure 11: Evaluation of the time, when the blind is active. Solar gains and effective $g$ values for a vertical facade in Würzburg, Germany (TRY5). The facade consists of the external white venetian blind in combination with the heat-mirror glazing. The control strategy is »cut-off«.

The average annual $g_{\text{eff, sunshading active}}$ for all orientations and the control strategy »cut-off« is 0.19 for TRY5 (Würzburg, Germany). For TRY3 (Berlin/ Essen, Germany) we found an average value of 0.20.
TRY5 (Würzburg), External white venetian blind + heat-mirror glazing

The facade consists of the external white venetian blind in combination with the heat-mirror glazing. The control strategy is »closed«.

Figure 12: Evaluation of the time, when the blind is active. Solar gains and effective g values for a vertical facade in Würzburg, Germany (TRY5).

The average annual $g_{eff, shading active}$ for all orientations and the control strategy »cut-off« is 0.04 for TRY5 (Würzburg, Germany).
The difference between the results for both control strategies shows, that the control strategy (or the behavior of the user) has a big influence on the solar gains. When the system is active, the gains differ by a factor of 5, depending on the control strategy!
Comparing the solar gains for north and south facades, it is found out that the summer solar gains per m² are higher for north oriented facades than for south oriented facades for the external blind and control strategies under consideration. The effect is caused by the hours with purely diffuse illumination. It proves the statement, that the diffuse irradiation must be taken into account.

6. CONCLUSIONS
With the presented methodology it is possible to make a comparative evaluation of sun-shading systems together with the associated control strategies. Whether a sun-shading system provides sufficient overheating protection or not depends on the building (window area, internal loads, ...) and has to be determined for each building individually. The results of the paper can be summarized in the following statements:
- The demands of the future user have to be taken into account in an early stage of the planning process. This means, that the planning team has to agree on a control strategy that fits with the priorities of the future users. The control strategy can be different for different sun-shading systems.
- For a realistic and reliable evaluation of the overheating protection it is necessary to take into account the angular distribution of the incident radiation. For this, the determination of the angle-dependent g value is necessary.
- The methodology developed at Fraunhofer-ISE has been validated for different sun-shading systems of the company Hüppe Form, Oldenburg, Germany. It allows a realistic and reliable evaluation of overheating protection with sun-shading devices.

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REFERENCES


