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Abstract – Solar shading devices can significantly reduce cooling loads, improve thermal comfort and reduce potential glare problems in commercial buildings. However, measured data or tools to facilitate a comparison among various shading devices have previously not been available to designers. The Solar Shading Project at Lund University was initiated in 1997 to increase the knowledge on shading devices. This paper describes results from an extensive measurement program and recent developments of the software tool ParaSol v 2.0. The total solar energy transmittance (g-value) of various shading devices has been estimated by means of measurements in a real climate using a double hot-box arrangement. Monitored results are shown for external products (awnings, Italian awnings, venetian blinds, horizontal slatted baffle, fabric screens, solar control films), interpane (between panes) and internal products (pleated curtains, roller blinds, venetian blinds, solar control films). The software tool ParaSol has been further developed to include all these types of products. In general, external shading devices are the best in reducing cooling loads, internal products are the worst, while interpane products fall between these two. Further, internal products must have a high reflectance in order to yield a low g-value. The monitored average g-value within each group (g-sunshade) was 0.3 for external products, 0.5 for interpane products and 0.6 for internal products. On average, external products are twice as good as internal products in reducing peak cooling loads. With the software tool ParaSol, it is possible to estimate the effective g-value of shading devices for various orientations in combination with an arbitrary glazing system. Further, effects on heating and cooling (both peak loads and annual energy demands) and operative temperatures of an office room can also be simulated.

1. INTRODUCTION

Commercial buildings with large glazed surfaces may easily suffer from overheating problems or large peak cooling loads. Solar shading devices can significantly reduce these cooling loads, improve thermal comfort and also reduce potential glare problems (Dubois, 2001). Due to lack of relevant data as to how well sunshades protect buildings against unwanted insolation, the Solar Shading project was initiated in 1997 at Lund University, Lund, Sweden. One aim of the Solar Shading project has been to measure the solar transmission properties of a large selection of solar shading devices available on today's market in order to provide comparable g-values measured under similar conditions. The measurements have been divided into three groups: external shading devices, devices between panes (interpane devices), and internal shading devices.

A design tool with the name ParaSol v 2.0 has also been completed during the project. The main purpose of the design tool is to be a simple but still accurate design aid for architects, building services consultants and other engineers. It can be used to study the potential of solar protection for different types of sunshades and also their influence on the building energy performance at an early design phase. Since this target group has a very varied technical background, the intention is to make a tool that is sufficiently advanced to produce relevant data, but not so complicated that the user introduces unnecessary errors in the input data or quite simply will not use the tool at all. This tool is mainly intended for simulations of buildings such as offices, schools and hospitals. (Wall & Bülow-Hübe, 2001 and 2003).

2. OUTDOOR MEASUREMENTS

2.1 Method

The measurements were performed in two well-insulated boxes, placed in a room at about 20°C. The boxes had a double-glazed unit (1.17 m × 1.17 m) which was in contact with the sun and the outdoor climate through a hole in the south wall of the building. See Figure 2.1.

A sealed insulated glass unit (4 mm – 12 mm – 4 mm, clear float) was used for external and internal shading products. For interpane products, a double-glazed unit was used (4 mm – 30 mm – 4 mm, clear float) which corresponds to a coupled window, typical of older Swedish buildings. The boxes were placed in Lund at 55.7°N.
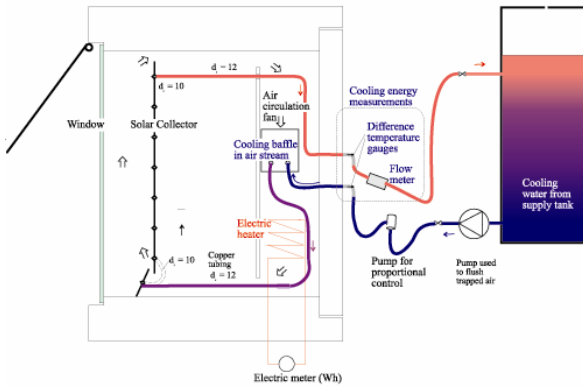
Figure 2.1   Hot-box and measuring system

A solar absorber (Sunstrip fins) was placed behind the window. The air between the absorber and the window, as well as the water in the pipes of the absorber, was temperature controlled with cooling and electrical heating. The air was held at around 20°C, approximately the same as for the room where the boxes were located, and was blown along the absorber to reduce the heat resistance between the air and the absorber. For the total solar energy transmittance, the temperature difference between the box and the outdoor air multiplied by the window U-value (from night measurements) was used. The heat balance for the box is:

$$Q_{sun} = Q_{cool} - Q_{el.heat} + Q_{window} + Q_{room} + Q_c \text{ (Eq. 2.1)}$$

where Q_{sun} is the total transmitted solar energy, Q_{cool} and $Q_{el.heat}$ are the measured cooling and heating energies. Q_{window} is the measured and calculated heat losses through the window. Q_{room} is the measured and calculated heat losses from the box to the room. Finally, Q_c is a correction term for the heat capacity of the box with respect to changes in the box temperature during the measurement period.

During the night Q_{sun} is zero which is used to calibrate the boxes. Equation 2.1 is used to calculate Q_{sun}, the total solar energy transmitted through sunshade and window. The total solar transmittance of this system is denoted g_{system} which is calculated by dividing Q_{sun} by the product of global solar radiation on the window I_G, and the area of the window A_w:

$$g_{system} = \frac{Q_{sun}}{I_G A_w} \qquad \text{(Eq. 2.2)}$$

The *g*-value of the window/sunshade system can (somewhat simplified) be regarded as the product of the window *g*-value and the sunshade *g*-value. We define the sunshade *g*-value as:

$$g_{sunshade} = \frac{g_{system}}{g_{window}} \qquad \text{(Eq. 2.3)}$$

The $g_{sunshade}$-value depends slightly on the type of window used. If the window is double glazed, $g_{sunshade}$ is the same as the shading coefficient which is sometimes used in connection with sunshades. In Sweden, a double-pane window is normally used as a reference for the shading coefficient. However, some countries use a single clear glazing as a reference. We use one box to measure the total transmittance of the sunshade and the other to measure the transmittance of only the window. All the results set out below are based on 5-minute mean values that have been smoothed out with a moving average of 50 minutes. In all cases, the global solar radiation on the facade was greater than 100 W/m^2.

The values reported in this section all apply to the hour with the highest solar altitude, i.e. at around 12 o'clock standard time. The estimated maximum measuring error was ± 5% of the calculated total transmittance, but was not less than ± 1%. However, the measurements have been performed throughout the year, and the effect of varying solar altitudes has not been corrected for.

2.1.1 External shading devices

Measurements reported here relate to: two awnings, two Italian awnings, two external venetian blinds, three screen fabrics, one horizontal slatted baffle, and a number of solar control films laminated on the external side of the glazing system. The two awnings (and the Italian awnings) were of the same type and geometry, but one had a light-coloured fabric (off-white) and the other a dark blue fabric. The awnings were tested in two positions, fully and partially extended. The external venetian blinds were silver coloured with slats 50 and 80 mm wide. Both blinds were tested fully lowered with the slats in two positions: horizontal and with slats at 45° to the window. More details about the products and the measurements are given in (Wall & Bülow-Hübe, 2001).

2.1.2 Interpane shading devices

The shading devices mounted between two clear panes were: venetian blinds (28 mm metal slats), two pleated curtains, two roller blinds (Texienne) and one screen fabric. Three different blind colours (blue, white and metal) and also several slat angles were studied. The two roller curtains tested were both of a light colour. The products are further described in (Wall & Bülow-Hübe, 2003)

2.1.3 Internal shading devices

The internal shading devices were mounted close to the inner side of the window. The products tested were venetian blinds, pleated curtains, roller blinds (both fabrics and solar control films), one screen fabric and

several solar control films applied directly on the inner pane. Several of the internal shading devices were identical to those measured between panes. The reflectance and transmittance of the fabrics and films were also measured with a spectrophotometer at Uppsala University.

2.2 Measurement results

Figure 2.2 summarizes the results of the g-value measurements for the three product groups external, interpane and internal shading devices. Although a large variation within each group is evident, external products generally have lower g-values than interpane and internal products. The regression line indicates that the average g-value ($g_{sunshade}$) is 0.29 for external, 0.48 for interpane and 0.62 for internal shading devices.
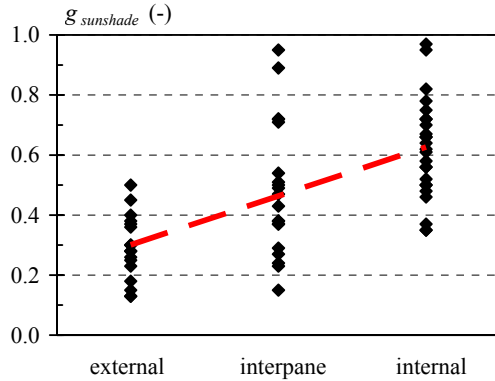

Figure 2.3 Effect of position of shading device on $g_{sunshade}$ for some interpane and internal products of various colours and slat angles.

Figure 2.2 Summary of all measurements of $g_{sunshade}$ for external, interpane and internal shading devices respectively.

Since some of the products are applicable as both interpane and internal devices, ten of them were measured in both positions, see Figure 2.3. For these products, $g_{sunshade}$ is on average 0.23 units lower for interpane than for internal placement.

In order to obtain a low $g_{sunshade}$ for internal solar shading devices, it is important that the fabric used has a light colour, i.e. a high solar reflectance, R_{sol}. This is demonstrated for ten roller blind fabrics in Figure 2.4. However, it must be kept in mind that the two products with the lowest g-values also have a very low visual transmittance, T_{vis}, of the order of 3-4 per cent, thus admitting very little daylight to the room behind. The product yielding the highest $g_{sunshade}$ (a dark blue roller curtain, H500-54) also admits very little daylight to the room ($T_{vis} < 1\%$), see Table 2.1. Here, the high g-value is a result of a high solar absorptance (about 80%). The product that provided the most daylight ($T_{vis} = 40\%$) was a semi-transparent roller blind (LS Ombra, white), and its $g_{sunshade}$ was 0.64.
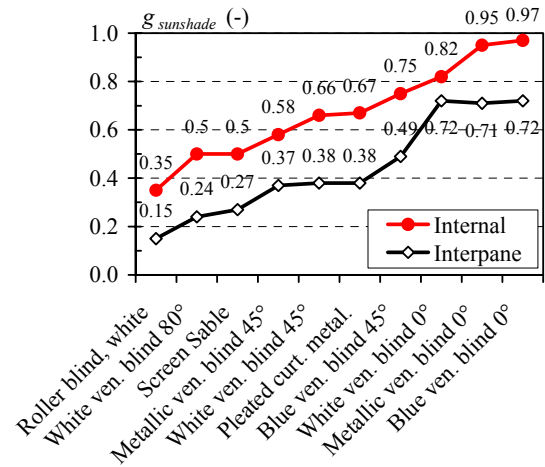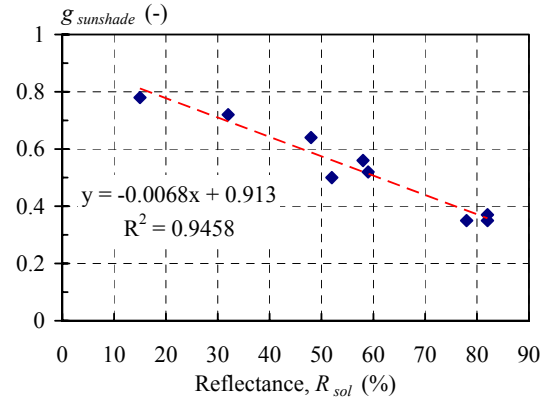

Figure 2.4 Relationship between $g_{sunshade}$ and solar reflectance, R_{sol}, of some internally mounted roller curtains.

Table 2.1 Results from optical measurements of some fabrics. T_{vis} is the visual transmittance (380 - 780 nm), T_{sol} the solar transmittance (300 - 2500 nm), R_{sol} the solar reflectance. The g-value of the sunshade when internally mounted is also shown.

Product	T_{vis} (-)	T_{sol} (-)	R_{sol} (-)	$g_{sunshade}$ (-)
LS Ombra, white	0.40	0.41	0.48	0.64
LS Optic, white	0.04	0.04	0.82	0.37
H 981-95	0.03	0.05	0.59	0.52
H 542-98	0.18	0.19	0.32	0.72
H 925-90	0.04	0.06	0.82	0.35
H 927-95	0.03	0.05	0.78	0.35
H 500-90	0.37	0.37	0.58	0.56
H 500-54	0.00	0.04	0.15	0.78
Hexcel Satine Sable	0.11	0.12	0.52	0.50

LS = Ludvig Svensson, H = Haglunds

3. SOLAR SHADING MODELS

Models for different types of sunshades have been developed in this project. Screens, roller blinds and venetian blinds are examples of interpane and internal shadings. Calculation models for external devices were developed during the first part of the project and reported earlier. (Wall & Bülow-Hübe, 2001).

New developments include the treatment of long wave transparent layers (shading devices) in combination with long wave opaque glass panes. Short wave transmittance, reflectance and absorptance as well as long wave radiation exchange are calculated in detail. Direct and diffuse transmittance and direct (specular) and diffuse reflection and absorption are treated.

Plane solar shading devices are calculated as plane layers, parallel with the glass panes. Although some plane shadings are air permeable, all internal and interpane plane sunshades are calculated as non-permeable. All air gaps/layers are also treated as closed (non-vented). Especially for internal sunshades, which are often mounted with an air gap, this is an important limitation. In reality, an open air gap will cause a larger heat transfer to the room by air movements. The calculation results will therefore show the lower limit of the g-value, such as a theoretical optimal performance.

Venetian blinds are also treated as plane layers regarding radiation (solar and IR). The optical properties of the layer are calculated by tracing an incoming beam between two adjacent slats through the layer. The slats are treated as plane (although usually slightly curved in reality). Both directly and diffusely reflected and transmitted radiation from the slats are considered when calculating the layer properties. Convection between the venetian blind and the adjacent layers is treated with a simplified model. How the calculations are made is described more in detail in the report (part 2) of the Solar Shading Project (Wall and Bülow-Hübe, 2003).

4. THE PARASOL SOFTWARE

The graphical user interface of ParaSol is based on a dynamic energy simulation engine named DEROB-LTH. The simulation engine is a monolithic, detailed hour-by-hour energy simulation program.

ParaSol can simulate different types of sunshades positioned either externally, interpane or internally.

4.1 General data about the program
Input data to ParaSol is given via a number of forms or windows. On each form there is a glossary and help function. The output of a simulation is in the form of diagrams to display the effectiveness of solar protection for sunshades and the combination of sunshades and windows, and diagrams to show different characteristics of the building energy performance. Thermal comfort can also be studied.

Different strategies for controlling sunshades as well as an air conditioning unit to heat or cool the inlet air have been added to this version of ParaSol. A simple control of sunshades based on solar radiation intensity on the façade has also been implemented.

ParaSol can be run in Swedish or English mode and is developed for the operating systems MS Windows 95/98/NT/2000/XP and is freely available over the internet at www.parasol.se.

Two different types of simulations can be run in ParaSol, *Solar transmittance* or *Energy balance.* Both simulations are dynamic and hourly for a period of one year.

4.2 Simulation of solar transmittance
The solar transmittance simulation calculates monthly averages of the g- and the *T-values* (i.e. total and primary solar energy transmittance) for the active sunshade-window system in a room at a specified site. ParaSol has a climatic library for a number of sites in mainly Europe. Using the software METEONORM from the company METEOTEST in Bern, Switzerland can produce climatic data for almost any site.

4.3 Energy balance simulation
The energy balance simulation calculates insolation, peak heating and cooling loads, annual and daily heating and cooling demands for the room and specified site. Required input data are thermostat set-points for heating and cooling (max. and min. temperatures), internal loads, ventilation rates and inlet air temperatures during work hours and nights /weekend respectively.

5. COMPARISON BETWEEN MEASUREMENTS AND PARASOL SIMULATIONS

Comparisons between the outdoor measurements and ParaSol simulations of g-values have been made for products for which optical properties were obtained (from spectral measurements at the Ångström Laboratory). The window construction was the same as described earlier, a double-pane clear window.

The two g-values are not directly comparable since the simulations are mean values for a whole month while the outdoor measurements shown here are mean values for a sunny day (around 8 hours). However, if the angle dependence of $g_{sunshade}$ is not too great, this difference is of less importance. (Note that the measurement results shown in Sec. 2 were values taken at noon).

The results from the comparison between outdoor measurements and the ParaSol simulations for the product groups interpane and internal products are shown in Figure 5.1. If the two values are equal, the point would be on the line $y = x$ in the diagram.
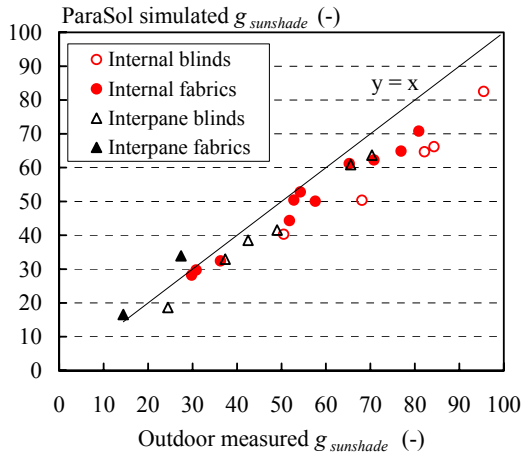
Figure 5.1   Comparison between outdoor measured and ParaSol simulated $g_{sunshade}$ for interpane and internal products.

One can notice that only the interpane fabrics gave values above the y = x -line, which means that the outdoor measurements gave lower $g_{sunshade}$ values than the Parasol simulations. For all internal applications, the outdoor measurements gave larger g-sunshade values than the Parasol simulations.

  For the internally mounted fabrics, the resulting outdoor measured $g_{sunshade}$ values are in the range 1-12%, on average 4-5% larger than the ParaSol simulated values. There is a strong correlation between the difference and the absorptance of the material, which can be seen in Figure 5.2. For instance, for a blue roller blind with A = 0.81, the measured result is 10.1 % higher than the simulated one, while for a white roller blind with A = 0.05, the difference is 1.4%. Two of the sunshades in Figure 5.2 have an open, air permeable structure and are therefore marked differently in the diagram. The tendency for these products is the same as for the other fabrics but the differences between the outdoor measurements and the Parasol simulations are somewhat larger. A theoretical explanation for this correlation is that if the convective heat transfer coefficient on the inside is larger than expected a larger proportion of the heat from the solar radiation absorbed by the sunshade will be transferred to the room and thereby increase the g-value. Also, if the air gap between the sunshade and the inner pane is not fully closed, air change between the gap and the inside could increase the g-value. Both these explanations could have contributed to the larger g-sunshade values for the outdoor measurements.

  For the internally mounted venetian blinds, the resulting outdoor measured $g_{sunshade}$ values are 10-18% (on average 15-16%) larger than the ParaSol simulated values. The reason for this could be the same as suggested for the fabrics, namely a high convective heat transfer coefficient on the inside.

The difference between the outdoor measurements and the ParaSol simulations need however to be further investigated. Measurements of temperatures of the different layers, which have been carried out for most of the measurement, could be used for such an analysis.
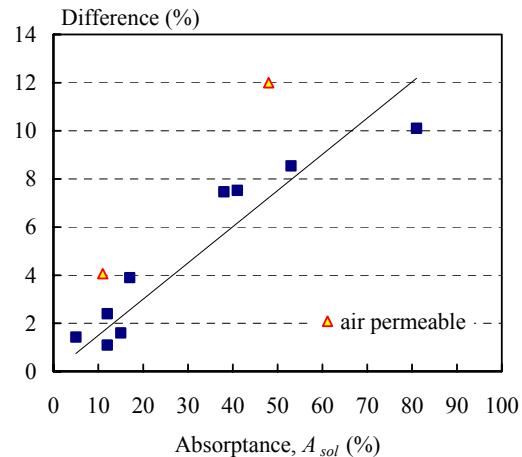

Figure 5.2   Difference between outdoor measured and ParaSol simulated $g_{sunshade}$ vs the material absorptance for internally mounted fabrics + a linear fit.

6. DISCUSSION

  External sunshades have a much greater potential to reduce cooling loads and unwanted solar gains than internal or interpane products, since the absorbed heat is mostly dissipated to the outdoor air. For internal products, it is essential to try to reflect the short wave solar radiation since the heat absorbed in the sunshade contributes to room overheating. However, depending on colour, slat angle position etc, there is a large variation in measured g-values within each product group of external, interpane and internal sunshades. For internal shading devices, it is demonstrated that the reflectance of the fabric is the most important parameter in obtaining low g-values. This is contrary to external shading devices where we have previously shown that, for example, dark awnings (with low reflectance and high absorptance) provide lower g-values than light ones (Wall & Bülow-Hübe, 2001).

  ParaSol v 2.0 is a new software tool which has been developed for easy and accurate comparisons of sunshades and windows. The agreement between the outdoor measurements and the Parasol simulations was rather good. The measured results for products between and on the inside of two window panes, except the internally mounted venetian blinds, gave $g_{sunshade}$ values 1-12% (on average 4-5%) larger than the ParaSol simulated values. The differences for the internally mounted fabrics were seen to have a strong correlation with the absorptance of the fabric material. A theoretical explanation for this is that the convective heat transfer

coefficient on the inside is large due to fan induced air movement.

For the internally mounted venetian blinds, the resulting outdoor measured $g_{sunshade}$ values are 10-18% (on average 15-16%) larger than the ParaSol simulated values. The reason for this could be the same as suggested for the fabrics, namely a high convective heat transfer coefficient on the inside. This effect would be enhanced for an air permeable structure like the venetian blinds. This indicates that further developments and validations need to be carried out especially regarding convective heat transfer which could have a large influence on both measurements and calculation results for internal shading devices.

Comparison between ParaSol results and measurements in a solar simulator have shown better agreement, but these results are not reported here, see instead (Wall & Bülow-Hübe, 2003).

7. CONCLUSIONS

The results indicate that the optical calculations of ParaSol are correctly performed except that the dependence of the optical properties of the products on angle of incidence is disregarded. The $g_{sunshade}$ values are however also dependent on the magnitude of the heat transfer coefficients between the sunshade, the window panes and the inside and outside surroundings, since they determine how much of the energy absorbed by the glass panes and the sunshade will be transferred to the room. The magnitude of the heat transfer coefficients is therefore important both for the measurements and for the ParaSol calculations/simulations.

In ParaSol v 2.0, all interpane or internal sunshades are assumed to be mounted with closed air gaps to the adjacent glass pane(s). Especially for internal sunshades, the combination of open air gaps and high absorptance would give larger $g_{sunshade}$ values.

The outdoor measurements of internal sunshades gave values larger than the simulated ones. This is assumed to be at least partly caused by a large inside convective heat transfer coefficient. However, one should not take for granted that the convective heat transfer coefficients used in the program are the true ones. For design purposes, it is therefore recommended that the $g_{sunshade}$ values for internal fabrics are multiplied by 1.1 and for internal blinds by 1.2.

In selecting shading products, one should also pay attention to the transmitted daylight and the effect on the view out. The internal products yielding low g-values admit almost no daylight into the room, and totally obstruct the view out, two of the main reasons for having a window.

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