Performance of shading devices in buildings - A collaboration between Lund University and Nordic manufacturers

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1. INTRODUCTION

Installation of solar control in office buildings, schools and hospitals instead of large cooling plants may reduce electricity consumption, reduce the use of freons and enhance comfort. It is a sound design principle that heat load should be *primarily* reduced through appropriate design of the building, i.e. through proper consideration of window orientation and window sizes, the use of sun shading, control strategies for sunshades, etc. If these measures are not sufficient, air conditioning has to be provided as an additional measure.

A good solution to overheating problems consists of controlling solar radiation incident on the building. Using solar-protective glazings is one simple solution which easily can be integrated into the building design (Olgyay and Olgyay 1957). Furthermore, the use of special glazing generates less construction and maintenance costs than shading devices (Soebarto and Degelman 1994). However, one major drawback of solar-protective glass is that it reduces solar gains in the building even during wintertime. Therefore, in countries with dominant heating requirements, moveable shading devices is a better solution (Dubois 1999).

Compared with windows, little is known at present of the thermal characteristics of sunshades and the effect of sunshading. This applies to internal sunshades, sunshades between panes of window glass, as well as external sunshades. Most manufacturers and retailers of sunshades can give only very rough estimated values regarding the solar radiation that is screened - or no values at all! A recent literature review (Dubois 1997) confirmed this and also concluded that the development of calculation methods to assess energy use and comfort in buildings equipped with shading devices still needs to be carried out. In order that air conditioning installations in buildings may be properly designed, it is obviously necessary to know what effect solar control will have. Therefore, a research project has been started which entails collaboration between the Department of Building Science at Lund University, the

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Swedish Solar Control Association and the Norwegian Solar Control Association. The project consists of measurements, calculations and the development of design tools in the form of a computer program and guidelines. The participation of Nordic manufacturers ensure that the work will be relevant for the building industry, which is very essential. This collaboration is also a way of improving the competence of the industry. The project started in January 1997 and is estimated to take five years.

The object of the project is to produce data on the practical performance of different sunshades. By means of measurements and calculations, the properties of different types of sunshades are obtained and collated in a database. These values are to be used as input values in a design tool which will be developed in the project. The design tool will provide the user with information at different levels of detail, e.g. monthly and hourly shading coefficients. In absence of a design tool, generalised performance have been calculated for specific situations. A proposal for a standardised laboratory method for the measurement of the physical properties of sunshades may also be developed. At present there is no such method, as has also been found in the course of international standardisation work (ISO, CEN).

So far, measurements have been made on a number of external sunshades and on sunshades between panes. Further measurements will include internal shades. In addition, the properties of different shadings will be measured in laboratory (Håkansson and Fredlund 1999). The measurements are continuously generalised through extensive calculations.

2 METHOD

The chosen method was divided in three separate steps. The first step was an in situ measurement together with selected laboratory measurements of the shading devices. Secondly, a computer model for the selected shading device was developed, validated and implemented in the program DEROB-LTH. The third step consisted of a parametric study based on the computer model for different angles, dates and orientations in order to obtain general values.

2.1 Measurements

A double guarded hotbox arrangement was used in the outdoor measurements. Two well insulated boxes were placed in a room at 20°C. One side of each box was fitted with a sealed double glazed unit (4-12-4 mm, clear glass) measuring 1.17 m x 1.17 m. This side was towards the outside, i.e. in contact with the sun and the outside climate. The windows faced towards the south. The schematic arrangement of these boxes, with the awning indicated, is shown in Figure 1.

The boxes were electrically heated and cooled with water which passed through a cooling coil and a solar collector positioned right behind the window. A 70 W fan in each box ensured that air circulated. The solar energy transmitted through the window was absorbed primarily by the solar collector and secondarily by the air and the walls of the box, and was then passed into the cooling coil. Every 30 seconds all relevant parameters were measured and then saved as 5 minute means which were subsequently smoothed with a moving average over 50 minutes.

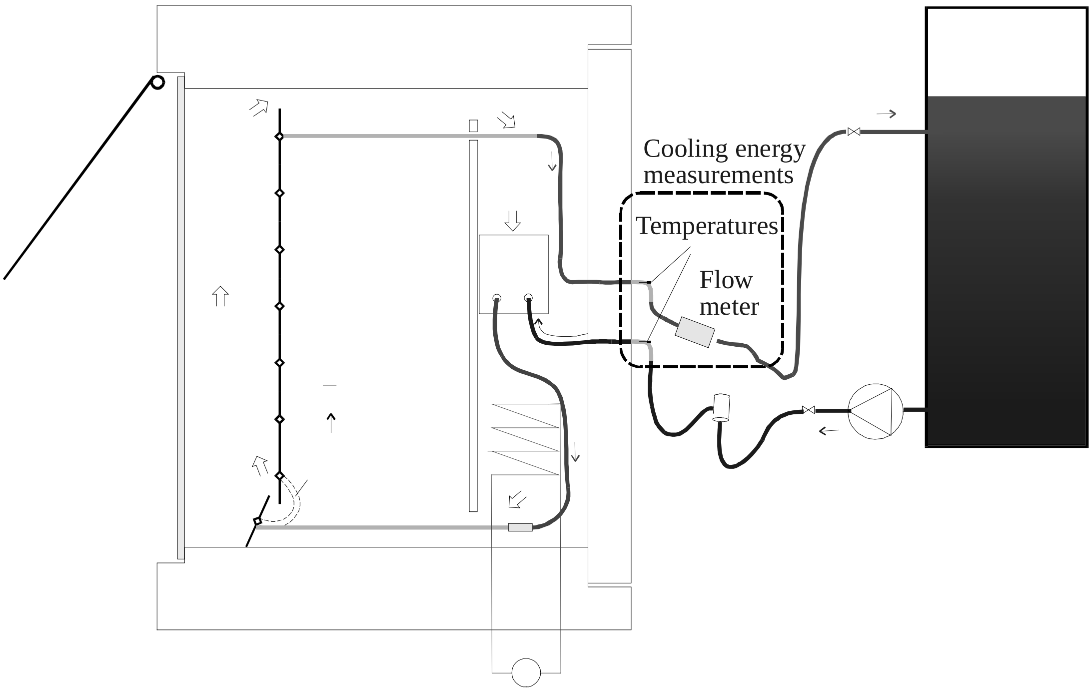

Figure 1 Guarded hotbox facing the ambient climate to the left.

The energy balance for a box is shown in equation (1):

$$Q_{cool} + Q_{window} + Q_{room} - Q_{electric} + Q_{capacity} = Q_{sun} \quad \text{(W)} \quad (1)$$

water cool	*heat flow through window*	*heat flow to room*	*electric heater*	*surface capacity*	*transmitted solar energy*

Depending on how Q_{window} is calculated, Q_{sun} has different interpretations. If Q_{window} is calculated from the conductive and longwave radiative heat flow between the panes, Q_{window} includes the primary solar transmittance and the energy absorbed in the interior pane. If Q_{window} is calculated from the theoretical U-value between the air in the box and the ambient air, Q_{window}

consists of the total transmitted solar energy (including the secondary transmission).

In order to calculate the total solar transmission G_{system} of the system, Q_{sun} calculated from the U-value is divided by the global solar radiation on the window I_G and the area A_w of the window.

$$G_{system} = \frac{Q_{sun}}{I_G A_w} \text{ (-)} \qquad (2)$$

Different methods can be employed in calculating the solar transmission for a certain sunshade. The easiest procedure is to assume that the total transmission is the product of the transmission for the various parts of the system:

$$G_{system} = G_{sunshade} \cdot G_{window} \qquad \text{(-)} \qquad (3)$$

Here $G_{sunshade}$ and G_{window} are the total solar energy transmittance for the sunshade and window respectively. It is somewhat inappropriate to use the term "transmission of sunshade" for $G_{sunshade}$, since reflections between the sunshade and the external pane, and between the facade and the sunshade, are included in this value. The value of $G_{sunshade}$ thus depends on the properties of the glass and the facade. However, $G_{sunshade}$ is a *term of practical value* which is presumably adequate in most cases except when an external pane of high or low reflectivity is used, or when the facade in question is very different from that used in the measurements and calculations.

2.2 Calibration of hotboxes

The cooling system in the boxes were calibrated with electric heaters. The overall thermal performance of the boxes was identified using linear multivariable regression on 4000 nighttime measurements. On the basis of these analyses the uncertainty in measuring the transmitted energy was estimated as less than 10%.

2.3 Computer models

The computer models of window and shading device are implemented as modules in the building simulation program DEROB-LTH. DEROB is a dynamic energy simulation program, originally from the University of Texas (Arumi-Noé 1979). The program has been developed continuously at the Department of Building Science, Lund University (Källblad 1998, 1999). The program uses hourly data and updates hourly solar position four times every month. The window and shading model has the following main characteristics:

- Coarse ray tracing and Fresnel calculation of the direct radiation.
- View factor and Fresnel calculation of the diffuse radiation.
- One thermal node for each pane.
- Shading device transmits and reflects diffusively.
- One thermal node approximating the thermal balance for all shadings.
- Long wave sky radiation included.

2.4 Verification of shading models

Figure 2 shows a comparison between measured and simulated energy balance for the test boxes. The shadings tested were a dark awning on box 1 and a light awning on box 2. The models were very satisfying. The relative error is less than 10%. The light awning model was slightly under-estimating the cooling for strong solar insolation. The reason for this might be the fact that the shading model does not permit solar radiation to be transmitted as direct radiation. The properties of the awning fabric was measured using an integrated sphere. The dark awning had a transmittance of 1% and the absorptance 90%. The light awning had a transmittance of 30% and the absorptance 30%.

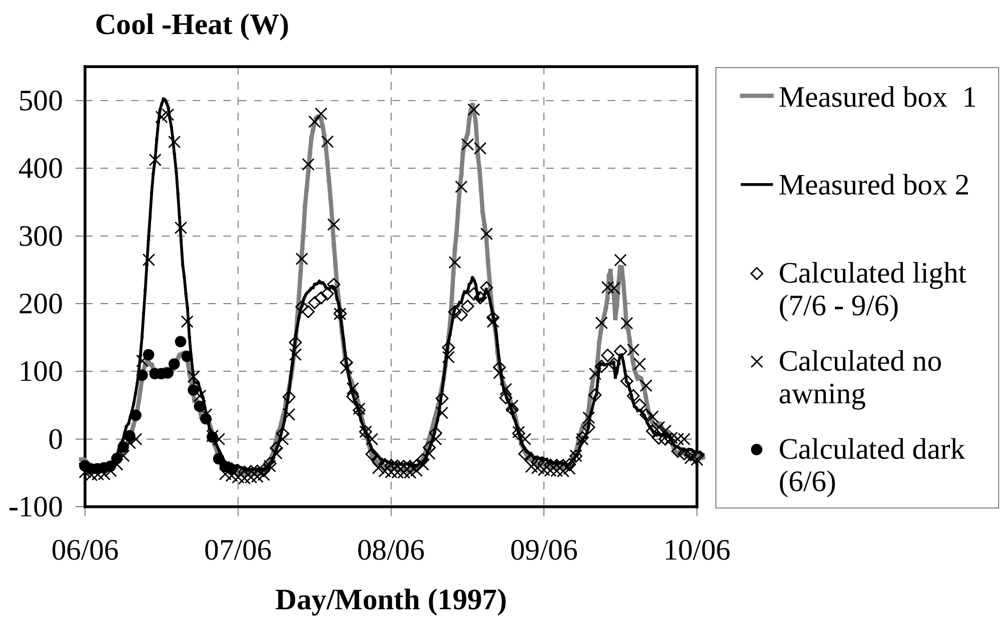

Figure 2 Comparison between measured and simulated energy balance for the test boxes. The shadings tested were a dark awning on box 1 (97-06-06 down, 97-06-07 up) and a light awning on box 2 (97-06-06 up, 97-06-07 down).

Similar measurements and tests were performed on external venetian blinds, Italian awnings, fixed overhangs and screens. Comparison between measurements and simulation for blinds and Italian awnings were most favourable. However, the screen comparison showed an

20% underestimation of the transmitted radiation for the model (Fredlund and Wall 1999).

2.4 Parametric study

The measurements made on the different shading devices gave $G_{sunshade}$ and other data for each device. However, these values were only exactly valid for that specific time and place when the measurement was taken. In order to make more general results, a series of simulations were made with the models for: awnings, fixed overhangs, Italian awnings and exterior venetian blinds. These simulations were made for a whole year for different locations and orientations. The approach used was to calculate a monthly energy average $G_{sunshade}$ and a monthly average $G_{sunshade}$ with a weighting factor of the solar insolation of the power of 10 for a specific orientation. With this weighting factor the effect of the device under maximal solar insolation was calculated, a useful factor when calculating peak loads.

3 RESULTS

The results from the simulation of a dark awning are shown in Figures 3 and 4. The simulations were performed with hourly data from Lund, Sweden 1988. It is clear from Figure 3 that the *G* value varies depending on the time of the day and the orientation. In Figure 4, monthly values are shown which clarifies that using only one *G* value for the whole year is not sufficient. However, *G* values for west and east orientations are very similar.

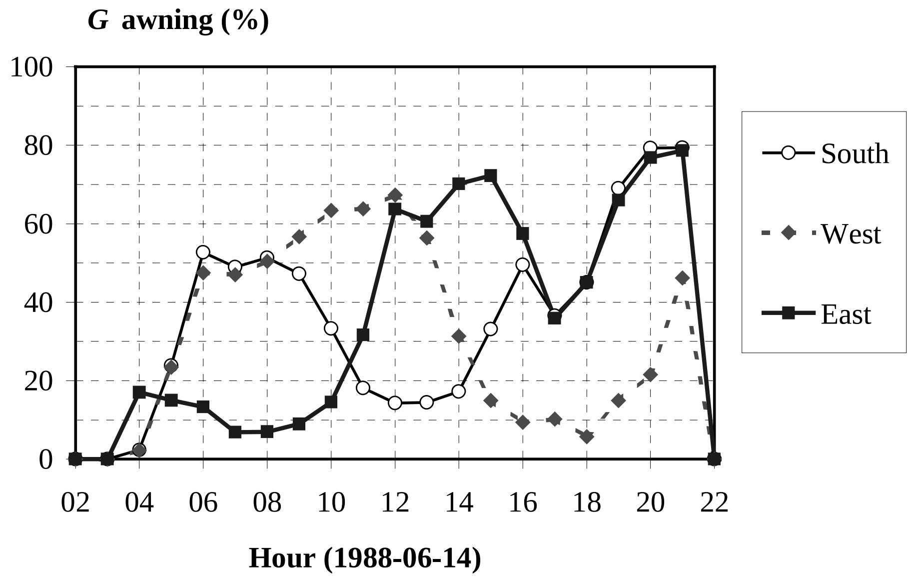

Figure 3 Hourly data from a simulation with dark awning (Lund 1988-06-14).

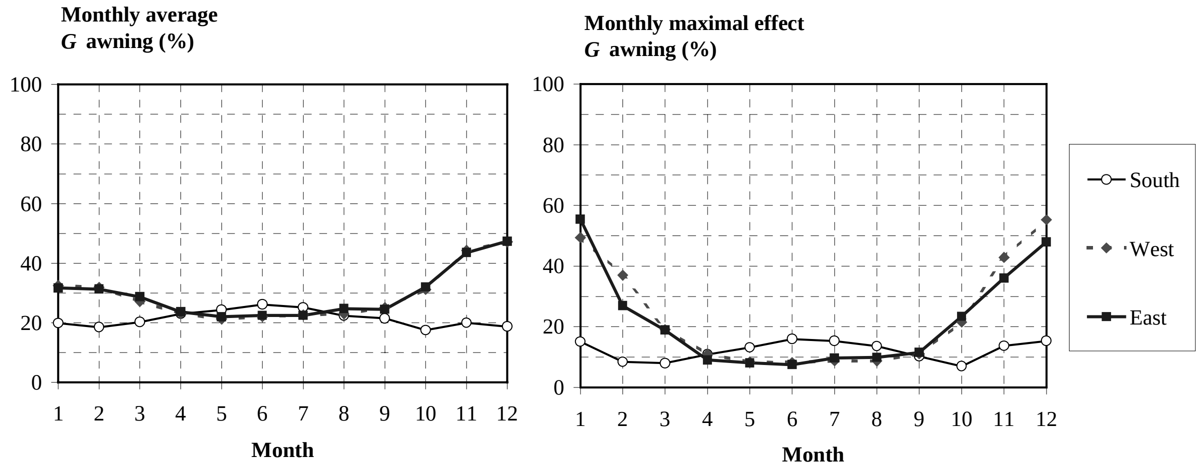

Figure 4 Monthly energy average and maximal effect *G* for the dark awning (Lund 1988).

4 DISCUSSION AND CONCLUSIONS

The calculation method used for exterior shadings is in good agreement with the outdoor measurements using a double guarded hotbox arrangement. The method is reliable for ordinary awnings as shown, but also for Italian awnings, external venetian blinds and fixed overhangs. However, the method for external screens is not yet acceptable.

Through extensive calculations, data are generalised to be included in a design tool for consultants. The calculation results showed that two shading coefficients are needed for each shading device, one to calculate the energy gains and one value to calculate the peak loads. The shading coefficient is specific for each shading device and window type, orientation, climate and season.

Measurements and calculations made so far indicate that sunshading can have a large effect on the energy balance. Since e.g. an office has mostly a cooling load sunshading can have a decisive influence on electricity use. Further outdoor measurements are in progress on sunshades between panes and will be followed by measurements on internal sunshades. A solar laboratory has been built and the optical properties of the shading materials will in addition be measured in this laboratory. In parallel, calculation methods are developed and validated through the measurements.

A design tool will be developed which will be able to assess the effect of sunshading on heating and cooling loads. Presumptive users are architects, HVAC engineers and those engaged in the solar control industry and building management. Further work will also enable development of new shading products and control strategies/systems and hopefully also include other very important aspects such as thermal comfort and daylighting.

Acknowledgements

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