Performance Analysis of External Shading Devices

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ABSTRACT: Protection of the building from unwanted solar gain is a key cooling strategy which is most readily achieved by blocking the sun’s rays before they reach the building. The aim of this work is to investigate the impact of external solar shading devices on the reduction of solar gains.

Within the Energy Department of Politecnico di Torino, an informatic tool named Ombre (Shadow) was developed, overcoming many limits of the existing software. In this paper, first results are presented concerning a parametric study carried out using Ombre in order to evaluate the influence of the geometry of the window-shading device system on the final performance of the system itself. The simulation was carried out for the latitude of Torino (45°N), using the results to create an easy to use manual for designing external shading devices.

Conference Topic: 2 Design strategies and tools
Keywords: energy, comfort, solar protection, shading device

1. INTRODUCTION

In the latest years sustainable architecture has brought to a new design approach that gives more relevance to the technologies in order to obtain a higher quality of the built environment and to reduce energy consumption.

To this purpose, shading devices play a fundamental role, since they contribute efficiently to solar radiation control.

Recently many procedures have been implemented to provide adequate tools to characterize the performance of shading devices. These procedures, of different complexity, have been integrated on the one hand in the technical standards concerning the evaluation of building energy performance, and, on the other hand, in specific informatic tools.

A broad analysis has been carried out on the existing software available for designers, trying to point out their limits and potentialities. The main limits concern the proposed interface, often not enough user friendly, the very simple typologies of shading devices considered, the type and accuracy of the results offered, and a poor use flexibility.

Within the Energy Department of Politecnico di Torino, a new software was therefore developed, able to calculate the Shading Factor which is the main performance parameter for shading devices.

In order to provide designers with more detailed indications, an informatic tool for classifying shading device performance was developed. It has been applied to the latitude of Torino (45°N) allowing to draw up an “easy to use” manual for designing external shading devices.

2. PERFORMANCE MODELLING

2.1 Shading Factor

The Shading Factor (FS) due to the presence of external shading devices as overhangs or side fins, can be defined as the ratio of the global solar radiation (direct, diffuse, reflected) received on the window in presence of shading devices to the global solar radiation which would be received on the window without them. It can be expressed as:

\[
FS = \frac{FS,b \cdot I_b + FS,d \cdot I_d + I_a}{I_b + I_d + I_a}
\]

where FS is the Shading Factor; FS,b is the Shading Factor for direct radiation; FS,d is the Shading Factor for diffuse radiation; I_b, I_d and I_a are respectively the direct, diffuse and reflected solar irradiance on the window without shading.

Ground reflected component is considered as totally incident on the window.

2.2 Direct Radiation

The Shading Factor due to direct radiation (FS,b), can be defined as the ratio of the sunlit area for direct radiation to the total area of the window.

A methodology for calculating the Shading Factor FS,b, first developed at the Florida Solar Energy Centre, Cape Canaveral [1] was improved by the authors.

The calculation procedure is based on the determination of the instantaneous shadow shapes cast by shading devices on a rectangular window.

The shadow shape is obtained from the geometry of the window-shading device system, the orientation and the tilt of the glazed surface and the sun position...
relative to the window, defined by the apparent solar altitude angle and the apparent solar azimuth angle.

For many typologies of shading device, all the shadow shapes that could be possibly cast on the window depending on the relative sun position were determined (e.g. in Figure 1 are reported all the shadow shape configurations for an overhang).

**Figure 1:** Shadow shapes of an overhang.

When determined the shaded area, it is possible to calculate by subtraction the sunlit area and thus the unshaded fraction:

$$F_{s,b} = \frac{A_{\text{unlit}}}{A_{\text{window}}} = \frac{A_{\text{window}} - A_{\text{shaded}}}{A_{\text{window}}}$$

### 2.3 Diffuse Radiation

The Shading Factor due to diffuse radiation ($F_{s,d}$) can be defined as the ratio of the sky vault seen by the window in presence and absence of shading devices. It can be calculated as:

$$F_{s,d} = \frac{\int_{\gamma_s=0}^{\pi/2} \int_{\phi_s=0}^{\pi/2} F_{s,b} \cos \theta \, d\phi_s \cos \gamma_s \, d\gamma_s}{\int_{\gamma_s=0}^{\pi/2} \int_{\phi_s=0}^{\pi/2} \cos \gamma_s \, d\gamma_s}$$

where $\phi_s$ is the solar azimuth, $\gamma_s$ is the solar height and $\theta$ is the incident angle of solar radiation.

This methodology considers an isotropic distribution for diffuse solar component. For its calculation, a simplified description of the sky vault has been obtained by dividing it in smallest sectors defined by angular aperture of 5 degree steps for solar altitude and 10 degree steps for azimuth.

The global Shading Factor for diffuse radiation $F_{s,d}$ is derived by summing up the contribute of each sector:

$$F_{s,d} = \frac{\sum_{i=1}^{16} \int_{\gamma_s=0}^{\pi/2} \int_{\phi_s=0}^{\pi/2} F_{s,b,i,j} \cos \theta \, d\phi_s \cos \gamma_s \, d\gamma_s \cos \gamma_{s,i} \, d\gamma_s}{\sum_{i=1}^{16} \int_{\gamma_s=0}^{\pi/2} \int_{\phi_s=0}^{\pi/2} \cos \gamma_s \, d\gamma_s \cos \gamma_{s,i} \, d\gamma_s}$$

### 2.4 Mean Shading Factor

In many applications solar gain analysis is performed over a certain period through simplified models requiring time average values of each parameter. For example, to predict the energy use for heating, it is necessary to know the amount of solar heat gain through the window during each winter month or during the entire heating season.

In these cases the Shading Factor has to be calculated as an average value over a reference period:

$$F_{s,m} = \frac{E_b \cdot F_{s,b,m} + E_d \cdot F_{s,d} + E_a}{E_b + E_d + E_a}$$

where $E_b$, $E_d$ and $E_a$ are respectively the direct, diffuse and reflected irradiation on the window over the considered period ($T$). $F_{s,b,m}$ can be calculated as:

$$F_{s,b,m} = \frac{\int_{0}^{T} E_{b,i} \, d\tau}{\int_{0}^{T} E_{b,i} \, d\tau}$$

The above integral can be discretised on hourly basis and separately applied to typical days representative of different periods (e.g. average monthly days).

Due to the complexity of this procedure, an informatic tool (Ombre) was developed.

### 2.5 Ombre

Ombre (Shadows) is a simple tool to analyse the performance of window-shading device systems. It allows anyone, even without experience in this field, to perform a detailed analysis by means of hour-by-hour simulation.

At the same time, Ombre is a very powerful tool, overcoming many limits of existing ones. It is able to analyse a variety of shading devices for anyhow tilted glazed surfaces.

In particular, it considers a rectangular window shaded by any of the following shading devices:

- rectangular overhang
- rectangular overhang with vertical projection
- rectangular overhang with sidewalls
- rectangular sidefins
- combined elements

The rectangular overhang can be anyhow tilted, located at any distance from the window, extending, even asymmetrically, beyond the edges of the window (Fig. 3).

**Figure 3:** Rectangular overhangs.
The vertical projection, suspended from the end of an overhang and parallel to the plane of the window, has no limitation in depth and is assumed to be full width of the overhang it is attached to (Fig. 4).

**Figure 4:** Overhangs with vertical projection.

The sidewalls are assumed as perpendicular to the plane of the window, linking the edge of the overhang (or the one of the vertical projection, if present) to the window plane at any distance from the top edge of the window (Fig. 5).

**Figure 5:** Overhangs with sidewalls.

The sidefins, perpendicular to the plane of the window, can be positioned on one or both sides of the window. In the last case, they can be differently sized. As well as overhang, they can be located at any distance from the window sill to its upper edge or beyond (Fig. 6).

**Figure 6:** Sidefins

A combination of overhang and sidefins can be also considered (Fig. 7).

**Figure 7:** Combined elements.

To calculate the Shading Factor, as previously defined, the required inputs are: the orientation and the geometry of the window-shading device system, the location, the day chosen for the simulation and the hourly values of direct and diffuse radiation on a horizontal plane. In Figure 8 the I/O interface is presented.

**Figure 8:** Interface of Ombre.

3. PARAMETRIC ANALYSIS OF OVERHANGS PERFORMANCE

To design a shading device, it is fundamental to quantify the influence of its geometry on shading effectiveness.

A case study was therefore defined, consisting of a square window with a horizontal overhang positioned on the upper edge of the window. A number of simulation were carried out varying the dimensions of the window-overhang system.

Both cases of finite overhangs (elements having the same width as the window) and infinite overhangs (high extension beyond window edges) were considered.

**Figure 9:** Scheme of the case study.

The analysis was referred to the summer design day (July, 21st) and to the latitude of Torino (45° N) for South and East orientation. It was assumed a ground reflection coefficient of 0.2.

The results of this parametric study are reported in the following paragraphs, presented in graphs reproducing the hourly profile of Shading Fraction for each configuration considered.

3.1 Depth of the overhang

Figure 10 reports the Shading Factor profile for finite and infinite overhangs of different depth, defined by the angle α between the window plane and the one linking the barycentre of the window to the end of the overhang.
It points out the considerable difference between the performance of finite and infinite elements in the condition of high value of apparent solar azimuth angle, condition that occurs early in the morning and late in the afternoon.

The difference tends to zero, instead, with the sun moving in front of the window, when more intense is the radiation incident on the window.

Figure 10: Shading Factor for finite and infinite overhangs of different depth exposed to South.

For East orientation, Figure 11 puts in evidence the poor performance of the horizontal overhang, that is near useless when the sun is low on the horizon.

For windows exposed to East, this condition occurs early in the morning, when higher is the value of the solar energy incident on the window. Shading effectiveness of an overhang becomes significant only late in the morning when solar irradiance is already decreased.

The performance of finite and infinite width systems, in this case, is very similar. The differences become significant late in the morning, with the sun moving to South.

3.2 Width of the overhang

Another important parameter to define designing an overhang is the width of the overhang above the window edge (\(\Delta W\)).

The results reported in Figures 12 and 13 show that, for overhangs East oriented, the width of the overhang does not affect the performance of the system, while it has to be carefully taken in consideration for windows exposed to South. In this case, however, there’s no strict correlation between the increment of this variable and the final performance of the system.

Figure 12: Shading Factor for finite overhangs of different width exposed to South.

Figure 13: Shading Factor for finite overhangs of different width exposed to East.

3.3 Height of the overhang

To analyse the relation between the height of the overhang above the window (\(\Delta H\)) and its shading performance, the overhang defined as the case study was tested at different distances from the window defined by 10 cm steps.

The results reported in Fig. 14, related to the South exposition, clearly show that there’s a direct correlation between the increments of this parameter and the shaded fraction, that remains almost constant during the day both in the case of finite and infinite elements. The same considerations are valid for East orientation too.

Figure 14: Shading Factor for finite and infinite overhangs at different height above the window exposed to South.
3.4 Window Shape

Concerning infinite overhangs applied to rectangular windows, the ratio between its depth to the window’s height is the only parameter influencing the performance of the system. This is no longer true, however, for finite elements. Overhang having the same width as the window, can result in substantial difference in the Shading Factor depending on the width of the window.

To quantify the influence of the window dimensions on the performance of a finite overhang, a series of simulations were performed for rectangular windows characterized by different ratio of its width (W) to its height (H).

As it was easily predictable, the results show an increasing influence of this parameter with the grown of the apparent solar azimuth angle, while it’s insignificant with the sun positioned directly in front of the window (Figure 15 and 16).

It is also evident that overhangs have a better performance if applied to a window having the horizontal dimension much bigger than the vertical one.

As the solar path differs in function of the latitude considered, when designing a shading device, it is necessary to refer to a specific location.

A comparison of the performance of different shading devices with reference to the latitude of Torino (45° N) and to the summer design day (21st July) has been performed using Ombre. The results have been arranged in a manual able to guide designers’ choice to the most convenient typology of shading device and to suggest proper dimensions to achieve desired performance.

The expositions considered were South, South-East, East and North-East (indications for last three orientations are valid respectively for South-West, West and North-West too).

Concerning the typology of shading devices, only element perpendicular to window plane were analysed.

As far as the geometry of the whole window-shading device system is regarded, some adimensional parameters were introduced. For infinite elements, being sufficient to specify the ratio between the depth D of the shading device and the height H or the width W of the window for horizontal and vertical elements respectively, $K_1 = D/H$ and $K_3 = D/W$ were defined.

For finite elements, being these parameters alone no longer sufficient to completely describe the geometry of the window-shading device system, further parameters were introduced. For horizontal overhangs, the width $\Delta W$ above window edge have been related to the height of the window through the parameter $K_2 = \Delta W/H$. For sidefins the height above window top edge $\Delta H$ have been related to the width of the window, through the parameter $K_2 = \Delta H/W$.

Furthermore to evaluate the influence of the geometry of the window and of its distance from the shading devices, the latter have been analysed at different distances from the window (for overhangs $\Delta H/H$ and for sidefins $\Delta W/W$ varying from 0 to 0.4), and for different geometries of the window itself, defined by the ratio between its horizontal $W$ and vertical $H$ dimension ($W/H$ varying from 0.5 to 3).

4.1 Use of the Manual

In the manual the results obtained by simulations have been first synthesized in an index reporting the maximum achievable Shading Factor for different expositions, window geometries and shading device typologies.

This data are presented with an histogram, where full bars refer to finite elements performance and the empty ones to the infinite ones.

In Figure 17 an extract from the index is reported.

4. A MANUAL FOR DESIGNING SOLAR SHADING DEVICES

Three main factors play a fundamental role in designing a solar shading device: the sun path, the exposition and the geometry of the whole window-shading device system.
Once decided the typology of shading device, user is guided to a section in the manual where more detailed information on the specific typology are provided.

The performance of the shading device is presented by diagrams built on the basis of the parameters previously defined (\(K_1, K_2, K_3, K_4\)), where each colour is associated to a specific Shading Factor value.

For an overhang, for example, the horizontal and the vertical axis of the diagram refer respectively to the parameter \(K_1\) and \(K_2\).

Any window - shading device system can be represented by a point on the \(K_1 - K_2\) diagram.

If a point is on a vertical iso-\(F_S\) curve, it is necessary to increase the overhang depth in order to get an improvement of the shading device effectiveness. On the opposite side, if a point is on a horizontal iso-\(F_S\) curve, it is necessary to increase the side overhang in order to get an improvement of the shading device effectiveness.

Besides that, if the point is in a zone in which iso-\(F_S\) curves are very distant, it can be not convenient to increase the shading device dimensions. On the opposite side, if the iso-\(F_S\) curves are very close to each other, a small increase of the shading device dimensions can yield a considerable reduction of incident radiation.

In Figure 18 and 19 the diagrams reporting the Shading Factor profile for overhangs and sidefins are respectively presented.

This methodology, so far applied only to the latitude of Torino, could become a model to extend to other locations.

CONCLUSIONS

The aim of this work was to provide designers with some useful information and new tools to project solar shading devices. In particular, an informatic tool was developed by the authors overcoming many limits of existing ones.

This software, called Ombre, has been used to perform a series of simulations for the latitude of Torino (45° N), and the results have been used to create an easy to use manual for designing external shading devices.

REFERENCES