A graphic method to evaluate shading effectiveness in windows and facades

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Abstract
The shading effectiveness of solar protections is determined by the percentual comparison of the shade area projected in the opening or facade, in relation to the total area of the unprotected window or facade. This study proposes a graphic tool to quantify the efficiency of solar control strategies of the openings and building facades for the shade elements proposed in an intertropical locality, in order to establish suitable prototypes according to different orientations.

The shading masks that are used for the evaluation and design of solar protection systems, permits to obtain a value, which would indicate its effectiveness, due to the fact that projections from shade devices obtained from the sunpaths in the celestial vault, don't correspond for all the points of the opening; but generally for the middle point (50% effectiveness) and or extremes of the base of the window (100% effectiveness).

Considering the limitations mentioned above, the shadow effectiveness protactor is proposed, which is based on the principles of the shading masks applied to multiple reference points obtained in the opening or facade surface, with an established percentage. **Taking** as starting point the shading mask of each prototype, effectiveness isolines were drawn (from 0 to 100%), through which the sunshine conditions of the window or facade for any moment of the day and year can quickly be determined.

The shadow effectiveness protactor for openings or facades constitutes a tool that permits its direct application in the design of buildings since it uses a solar diagram as base point, which is very common in the studies of insolation in architecture. The instrument can be as accurate as is required, through the incorporation of reference lines corresponding to intermediate percentages of effectiveness and it is also applicable in cases located in any latitude, using the appropiate solar chart.
Keywords: Solar control, building envelope, energy in buildings, thermal comfort, design tools.

1 Introduction

The effectiveness of the solar protections from the point of view of the shading of the openings and of the facades of the buildings, is intimately related to its efficiency in the control of the incidence of the direct solar radiation. This is determined by the comparison among the area of projected shadows on the window or facade surface considered by the solar protection devices, with respect to the total area of the window or unprotected facade, expressed in the form of index or of percentage [1]. The average of the hourly amounts obtained for a given direction, corresponds to the effectiveness of the system for the stipulated date.

The calculation of the factors and or percentages of shading effectiveness with a high degree of precision, can be by an analytical or graphical method, through numerical processing in worksheets, graph simulation of the shadow paterns in facade and the calculation of the shadowed area in the opening produced by the solar protection through Autocad or other computerized programs elaborated for such means, such as CODYBA version 5.0 [2]. Other programs exist in the market, such as AutoVision, Accurender, ArchiCad, 3D StudioVis, etc. that permit to accomplish the simulation of the effects of the insolation, but don't permit the quantification of the efficiency of the shade elements.

The calculation of the effectiveness of a solar control device as compared to the direct solar radiation, using tabular data and / or the drawing of the standards of the shading, is dificult, laborious and slow that escapes to the ordinary labor of the architect. Considering these disadvantages and limitations, together with the inavailability in tropical developing countries, of specialized programs that permit these calculations, in this work is presented a versatile graph tool: the effectiveness shading protactor. This is based on the representation principle of the shade masks of the solar obstructions and permmits to determine the percentage of effectiveness in an single reading and with sufficient approximation for any direction, hour and date of the year, reasons by which it can be of great usefulness for the architectect and engineer. These effectiveness protactors, are used in an analogous way to the graphs used to determine the shadow angles and direct solar radiation for facades [3].

2. Methodology

2.1 Determination of effectiveness isolines on the surface of the opening or facade.

The isolines of effectiveness constitute geometric places of the points of the surface of the opening that have the same percentage of efficiency shading before the existence of a given solar obstruction. These lines are obtained as the representation from a series of shadows generated by the protective element on the surface of the window, which are characterized by having the same coverage area, taking as reference the shadow projected by the ends of the protection, in frontal vertical projection view.

The isolines are fictitious path lines of the shadows projected by the ends of the element of solar control that correspond to a given percentage of effectiveness. In the case of an overhang, the equal efficiency lines constitute parabolic configuration curves whose extreme points superior (A) and inferior (B) define respectively, a square or rectangular shadow - according to the proportions of the opening- and triangular areas which are equivalent to the percentage of stipulated window surface covered. The intermediate points of the isolines generate a series of shadows in a trapezoidal shape equivalent in surface area, which can be traced through the use of computer drawing programs of great precision such as Autocad. See Figure 1.

It is important to point out that the shadows that are projected outside of the opening (B'), but whose address coincides with one of the inferior extreme points of the opening (B), will always generate the same form and dimension of the shadow on the surface of the window. See Figure 1. In this case, the reference will be the frontal vertical shadow angle that defines that plane that contains all the solar beams that divide the window according to the stipulated proportion.

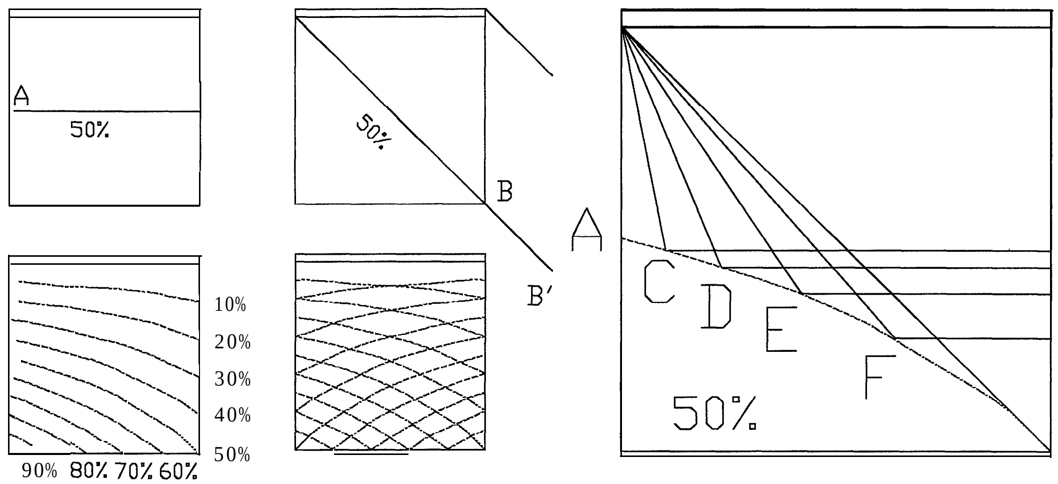

Figure 1.- Determination of the effectiveness isolines generated by a horizontal shade element for an opening

What is previously explained in the representation of the isolines of effectiveness for the particular case of the openings is valid in application to other scales, as in the case of the facades of the building, where solar protection devices exist or adjacent architectural volumes exist that generate shadows, such as is shown in Figure 2.

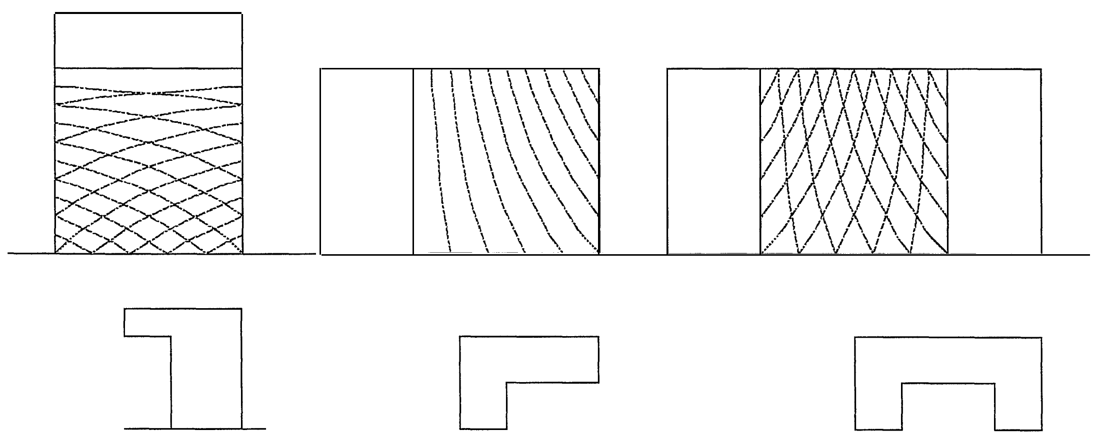

Figure 2.- Isolines of shadow effectiveness generated by superior and lateral volumes that project shadows on the surface of the facades

2.2 Geometric spatial - conception of the shadow effectiveness protactor.

The shading masks of the solar protection systems traditionally are built projecting toward the celestial vault opaque devices of one (< 100% effectiveness) or two points of view (100% of effectiveness) located in the extreme inferior of the opening that will be protected [4]. In our case, to determine the hemispheric projection of the isolines of effectiveness - obtained in the shadow receiving surfaces -, it is required to determine several observation points located on each one of the equal effectiveness lines, as of those which are traced visuals taking as direction the extreme(s) of the solar protection until it intersects with the celestial sphere. Thereinafter, the celestial isolines obtained to be projected stereografically on the horizon plane, generate the effectiveness protactor for the shading.

This graphic protactor constitutes a multiple projection system of solar protections obtained from the celestial vault from each one of the points that describes the different isolines. In this process, several series are obtained from superposed shading masks which upon joining them, generate at the same time, isolines that permit to establish the percentage of protection effectiveness of the opening or in its defect, the percentage of direct solar radiation that the surface of the opening receives for the stipulated solar protection, according to the established ranges (for example, increases of 10%).

In the case of overhangs, the system of isolines traced on the protactor generates a structure in concentric and symmetrical form. The lowest levels of effectiveness in the projection of the shadow, responds to an almost semicircular curve that when it goes through the lengthening and compressing processes the efficiency range is increased until defining a rectiline (for 100%). In the case of vertical elements it adopts a predominantly radial and symmetrical structure, except for the isolines of the highest levels of those which effectiveness become semiconcentrics. See Figure 3.

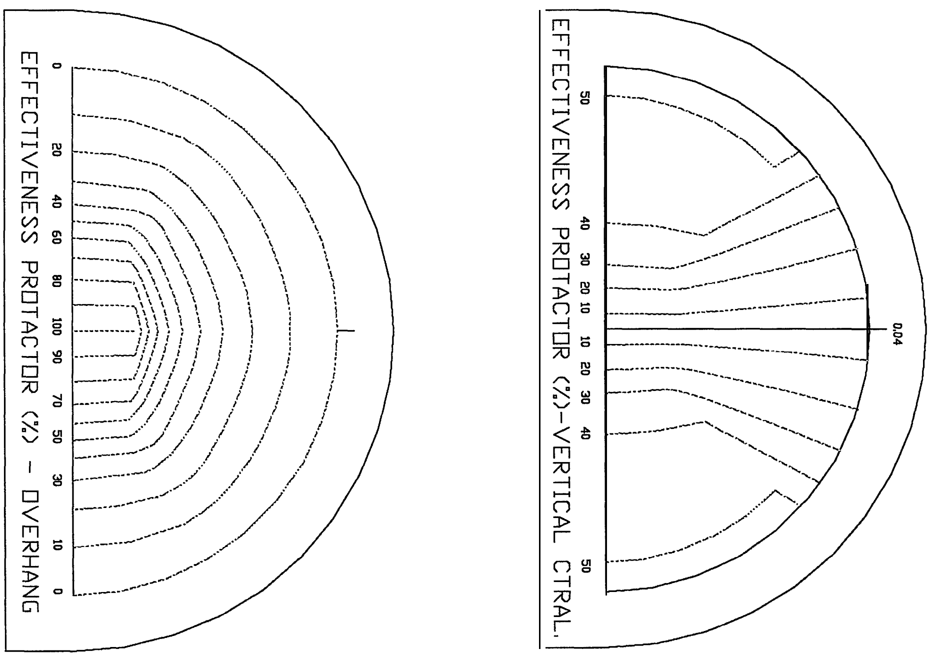

Figure 3.- Effectiveness protactor for a horizontal (left) and a vertical central solar protection (right) equivalent to the 50% of the surface of a squared configuration window.

2.3. **Tracing of the effectiveness protactor from the analytical calculation of the points of the isolines.**

Continuing the previous considerations and appealing to the principles of trigonometry applied to the incident solar beam and to the shadow generated by the extreme points of the protective element, the coordinates of a fictitious sun whose apparent movement will describe in facade the isoline corresponding to the percentage of stipulated effectiveness can be determined, in function of the solar altitude angles and of the horizontal shadow angle. With these two coordinates can be established the position of the apparent sun in the celestial vault and the shadow thrown by one of the extremes of the solar protection element. In Figures 4 and 5 are illustrated the different angles and dimensions to consider in the case of an overhang and a vertical device in a central position.

Using equations that result from applying spherical and flat trigonometry to the solar beam, taking as reference the corresponding plans of the horizon of the place[5], of the facade of the building [6] and of the solar protection, can be obtained the intermediate reference points (C, D, E, F...) that permit the tracing of the isoline on the window as well as in the protactor. The coordinate system of each point is defined by frontal, lateral and horizontal angles of shadow and the solar incidence angle on the facade. See Figures 4 to 6.

Below are presented the data and the analytical expressions that were used for the setup of the worksheets of the angles and projected shades.(See the nomenclature at the end of the work)

2.3.1. Data:

g, B, As, HSA

2.3.2. Unknown:

1) For horizontal shade elements:

$$d = g / \cos HSA \quad (1)$$

$$xs = d \text{ sen } HSA \quad (2)$$

$$b = B - xs \quad (3)$$

$$ys = 2A / (B + b) \quad (4)$$

2) For vertical shade Elements:

$$d = g / \cos HSA \quad (1)$$

$$b = 2 As / (g + \text{sen } HSA - B) \quad (5)$$

$$ys = B - b \quad (6)$$

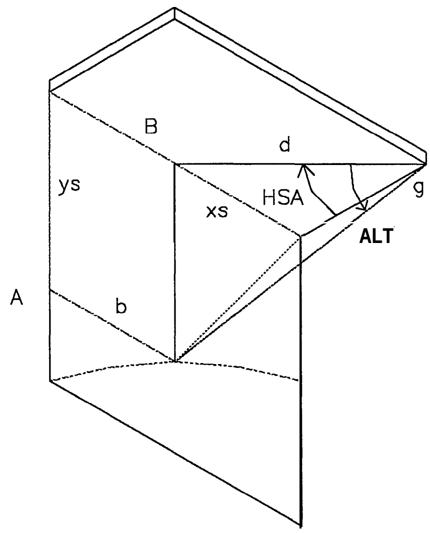

Figure 4.- Angle relationships among the solar horizontal protection elements and the shadows projected in the surface of the window.

3) For isolines representation:

$$ALT = Atan\ (ys / d) \quad (7)$$

$$FSA = Atan\ (cos\ ALT\ sen\ HSA) \quad (8)$$

$$FSACAD = 180^{\circ} + FSA \quad (9)$$
(if FSA is negative)

$$FSACAD = 360" - FSA \quad (10)$$
(if FSA is positive)

$$INC = Acos\ (cos\ HSA\ cos\ ALT) \quad (11)$$

$$S = g\ tan\ INC \quad (12)$$

4) For protactor isolines representation:

$$LSA = Atan\ (tan\ ALT\ cos\ HSA) \quad (13)$$

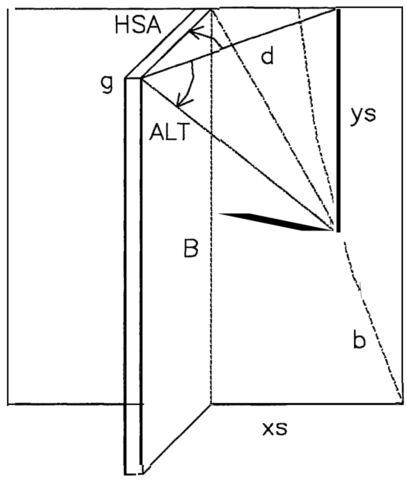

Figure 5.- Angle relationships among the solar vertical protection elements and the shadows projected in the surface of the window

In the cases of solar protections that are located in a central position on the surface of the opening, as in the prototype of a vertical element, we will consider within the shadow area to calculate, the thickness of the same protection element that, in the case of the overhangs, was not taken into account by virtue of the fact that they were located outside of the surface of the window. Because of this, for example, in the vertical protection the horizontal extreme shade for an effectiveness of 50% will not divide exactly by half the openings to protect, but at a smaller distance; while for an extreme oblique shadow in the order of 50%, generates a trapezoidal configuration instead of triangular. See figure 7.

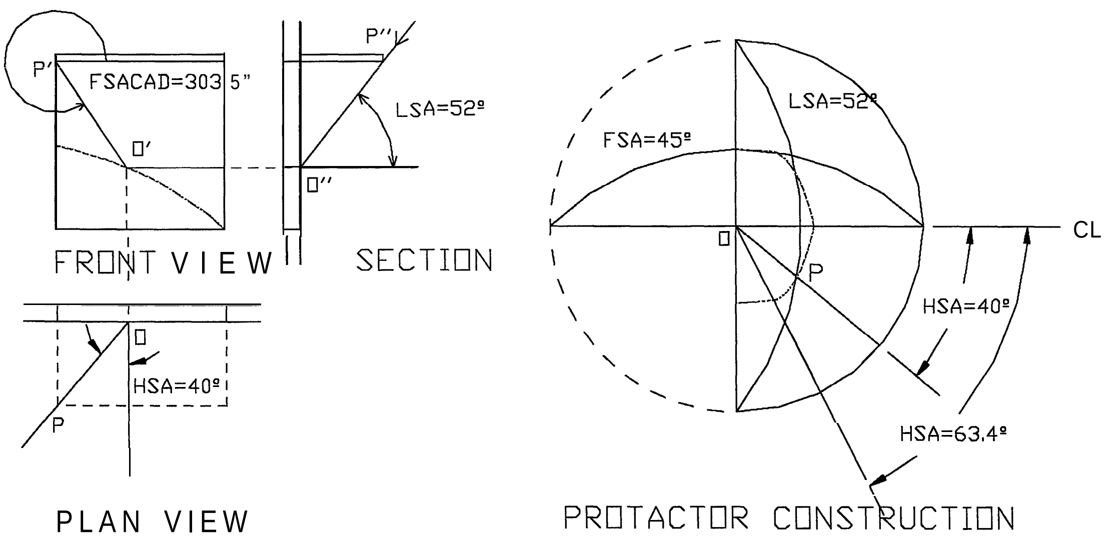

Figure 6.- Required shadow angles and traced of the isolines in the effectiveness protactor.

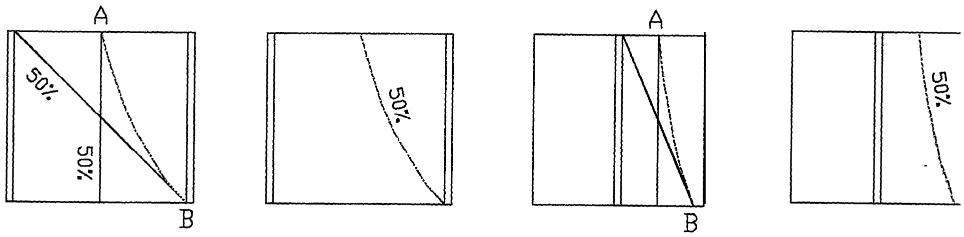

Figure 7.- Effectiveness isolines in the shading of the opening for a central and lateral vertical protections.

3 Discussion

It is evident that for each solar protection system to consider, there will exist a design for its respective effectiveness protactor, something which supposes a moderately laborious task, compared with the simulation method graph. Once its representation is obtained, it will permit the evaluation of infinite cases attending any direction of the window, hour, date of the year and latitude (using the corresponding solar diagram).

Because in Autocad, the representation process graph and the calculation is very slow, for the elaboration of the effectiveness protactor manually, a computerized program designed for this will be required, handling the Lisp language, in the same Cad package.

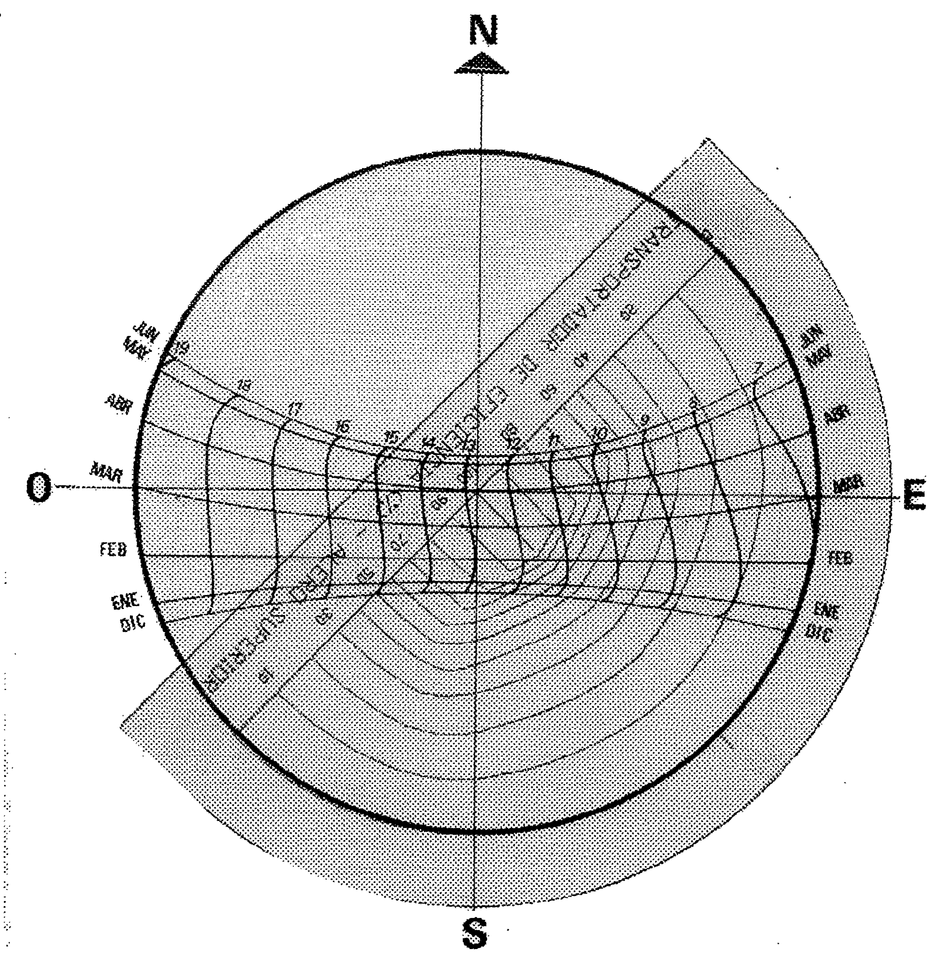

Figure 8.- Assembly of the effectiveness protactor with the stereographic solar graph for the study of an opening with direction southeast.

4 Conclusions

l)The effectiveness protactor in the openings shading constitutes a tool that permits its direct application in the architectural design since it uses as base a solar diagram, very common in the studies of insolation.

2) The overlapping of the isolines of the protactor with the reference lines for the different apparent solar paths, permits to quantify with good approximation the value of the hourly effectiveness of a solar protector. See Figure 8

3) These tools can be applied in scale models, to evaluate the insolation conditions in facades and or roofs, two-dimensional devices of solar protection for facades, or volumetric studies for the purpose of shading.

5 Acknowledgements

To the Consejo de Desarrollo Científico y Humanístico (CONDES) of La Universidad del Zulia by the financing of the research project “Control of thermal gain in the openings of the buildings” , of which is extracted the present paper.

6 Nomenclature

g	Depth of horizontal or vertical shade element
B	Horizontal dimension of the opening (overhang case) or vertical dimension of the window (vertical fin case)
As	Area of the projected shadow
HSA	Horizontal shadow angle
ALT	Solar altitude angle
FSA	Frontal vertical shadow angle
FSACAD	Frontal vertical shadow angle according to Autocad convention
LSA	Lateral vertical shadow angle
INC	Solar incidence angle
S	Length of the projected shadow for the segment g of solar protection

7 References

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