NEW MS-WINDOWS-BASED EDUCATIONAL SOFTWARE FOR TEACHING THE SUNPATH DIAGRAM AND SHADING MASK PROTRACTOR.

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ABSTRACT

The well-known versions of the sunpath diagrams and shading mask protractors that appear in the AIA's Architectural Graphics Standards are based on the equidistant projections and use a shading mask protractor developed by Olgyay and Olgyay at Princeton University in the 1950s. A designer using the AIA's Graphics Standards book, or other printed versions of the sunpath diagram must select the nearest latitude, make photocopies of the appropriate sunpath diagram and shading mask protractor, and then overlay the shading mask protractor upon the diagram in the proper orientation. The outline of the shading device is then transcribed upon the shading mask, aligned at the proper orientation for the facade in which the window is being analyzed, and placed on top of the sunpath diagram to determine if a point centered at the base of the window is exposed to direct sunlight. Obviously, teaching this process to architects and engineers is tedious and error-prone since the students must calculate several angles to ascertain whether or not a given shading device is going to work as planned and then painstakingly transcribe their calculations onto the printed sunpath diagram and shading mask protractor.

This paper describes a new MS-Windows-based educational software package that has been developed to fast-track the learning and use of the sunpath diagram and shading mask protractor which is based on previously published equations for plotting the sunpath diagram and shading mask protractor. Examples will be provided that demonstrate some basic configurations of shading devices that are often misrepresented in the standard literature.

INTRODUCTION

The sunpath diagram and shading mask protractor are well known graphic formats that have traditionally been used by architects and engineers to analyze whether or not a solar shading device will block direct sunlight on a given point in the plane of an exterior window. The sunpath diagram is a two-dimensional graphical representation of the three-dimensional path of the sun across the sky's hemispherical vault for a given latitude. In the sunpath diagram the three-dimensional sky dome is condensed onto a two-dimensional circular plan view where the sun's path becomes a series of elliptical curves. When a shading mask protractor template is superimposed upon the sunpath diagram, and oriented with respect to the proper off-south orientation to represent a window in a building's facade, the combined diagrams indicate those times of the year when direct sunlight does or does not strike a point centered at the lower edge of the window. The diagrams also allow for the impact of shading devices, such as overhanging protrusions from the building (i.e., fins or eyebrows), to be accurately plotted upon the shading mask protractor and superimposed on the sunpath diagram. The shading from adjacent buildings and nearby foilage can also be evaluated.

The origin of the sunpath diagram does not lie in the field of architecture. According to Olgyay and Olgyay (1957) it was first used by astronomers more than 400 years ago who published their early format in the 1531 "Rudimenta Mathematica" by Basel. The primary purpose of these early sun graphs was their use as a concise graph that indicated the sunrise and sunset times throughout the year at a given latitude.

In general, research concerning the plotting and analysis of shading devices peaked during the 1930 to 1960 time period. Various devices for physically measuring the effect of different shading devices on a window were developed including the heliodon, and thermoheliodon at Princeton University, and sun machine at the University of Kansas (Olgyay and Olgyay 1957). Interest picked up again during the later 1970s and early 1980s at the height of the solar years. However, aside from a few novel techniques for plotting the sun's path interest in shading analysis dropped off rapidly as the US government's funding for solar research plummeted in the mid 1980s. For additional reading on alternative methods for viewing the sun's path see the book by Mazria (1979), the solar text by Duffie and Beckman (1991), or the appendix to the Stein and Reynolds (1992) environmental systems book.

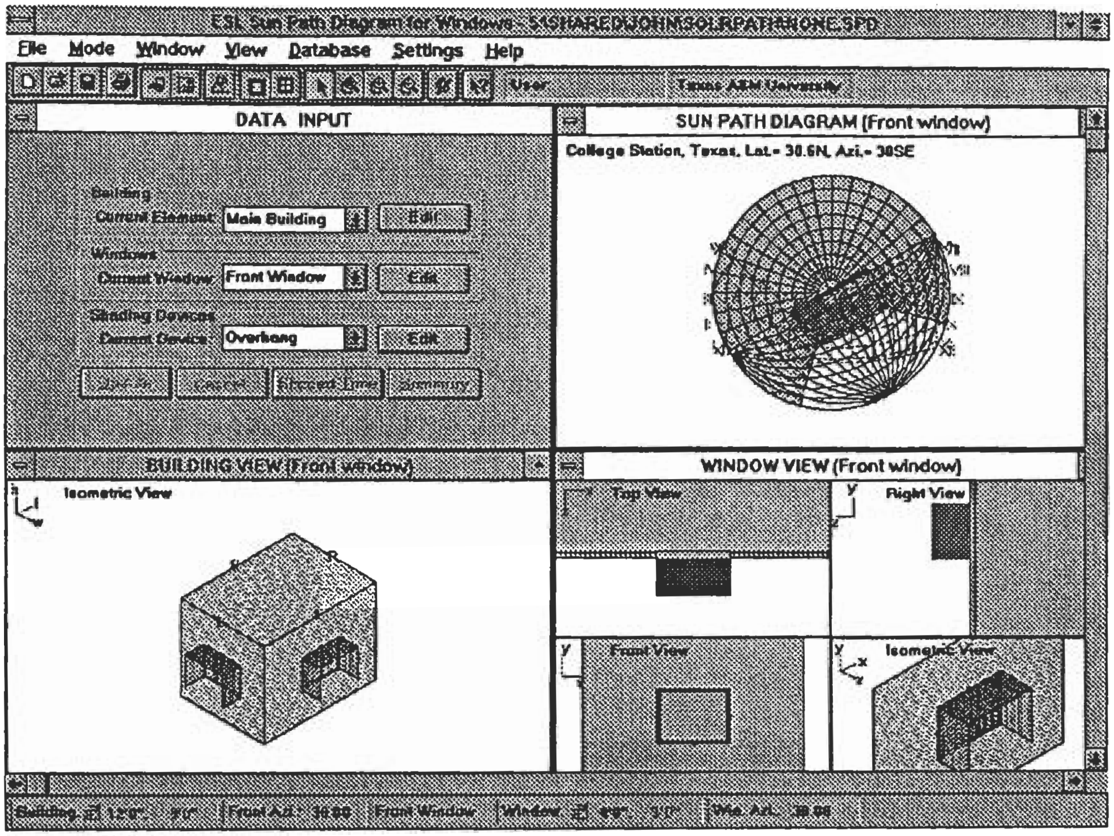

FIGURE 1: Opening screen for the solar shading analysis program. This figure shows the opening screen for the sunpath shading analysis program. All data entry is made in the "data input" screen. Modifications to the shading devices are shown on the various views of the building and the effect of the shading is shown on the combined sunpath diagram and shading mask protractor.

The well-photocopied versions of sunpath diagrams and shading mask protractors that appear in the AIA's Architectural Graphic Standards (Ramsey and Sleeper 1994) are based on the equidistant projections and the shading mask protractor which the Olgyays developed [1]. A designer using the AIA's Graphics Standards book must select the nearest latitude, make photocopies of the appropriate sunpath diagram and shading mask protractor, overlay the shading mask protractor upon the diagram and rotate the shading mask protractor until the proper off-south orientation is obtained. The outline of the shading device is then drawn using the shading mask protractor and aligned at the proper off-south orientation for the facade in which the window is being analyzed. Careful attention must be paid to select the correct construction lines on the shading mask protractor.

As originally intended, several additional overlays were developed that illustrated the intensity of direct normal and diffuse radiation on a horizontal surface. These overlay could also be superimposed upon the diagrams to allow for an analysis of the thermal effects of the solar energy that was incident on the window. In practice the radiation calculators[2] have been replaced by computer software that calculates the total incident solar radiation upon a window's surface at varying latitudes and orientations. A well-documented review of the different methods has been presented by McCluney (1995). Considerable information is also contained in the 1993 ASHRAE Handbook of Fundamentals concerning the evaluation of the heat gain or heat loss through windows (ASHRAE 1993). Until recently, however, the construction of the equidistant sunpath diagram and

[1] There are several techniques for plotting the sun's path upon a flat 2-D projection including orthographic projection, stereographic projection, and equidistant projection. The actual construction lines for the shading mask protractor have been physically verified using photographs taken with a "fisheye" lens, or globoscope which can be superimposed directly upon the sunpath diagram. Illustrations of this device are shown in Olgyay's book on pp. 46-47. The term "equidistant" refers to the equidistant spacing of the altitude lines (i.e., concentric circles) on the sunpath diagram.

[2] This terminology is from the Olgyays and refers to the graphical "calculators" that were illustrated in their book on pp. 60-63.

superimposed shading mask protractor remained largely manual task.

The inconvenience of the traditional methods of photocopying the traditional equidistant projection, sunpath diagrams can now be bypassed with the use of a series of simple algorithms that lend themselves readily to a computer program (McWatters and Haberl, 1994a; 1994b; 1995). With such a program the user only needs to enter the building latitude, along with dimensions of the window and shading devices if any, and the program produces the sunpath diagram and shading mask protractor on a single graph. The remainder of this paper describes the use of a MS-Windows-based program that automatically renders the sunpath diagram and shading mask protractor in a convenient to use software package that includes a tutorial on how the sunpath and shading mask protrotractor are constructed.

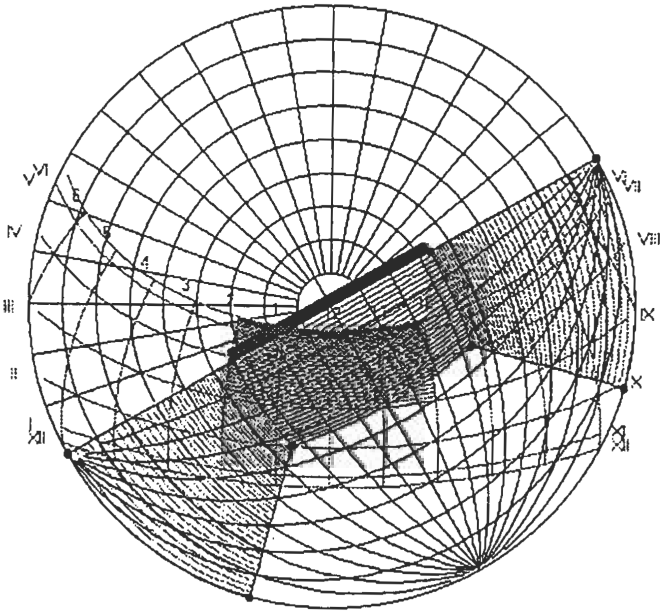

FIGURE 2: Close-up of the Combined Sunpath Diagram and Shading Mask Protractor. This figure shows the combined sunpath diagram and shading mask protractor for the shading devices shown on the front facade in Figure 1 for a facade oriented 30 degrees east of south located at 30.3 degrees north latitude.

USING THE MS-WINDOWS BASED SHADING ANALYSIS PROGRAM

The sunpath diagram and shading mask protractor represents an ingenious graphical overlay that simplifies the display and understanding of two hemisperical coordinate systems. The first of these is the shading mask protractor which represents the hemispherical view that one could obtained if a photo could be taken with a fisheye-lens camera that is facing upward, centered at the bottom of the window being analyzed. The view that is seen with such a lens forms a circle that distorts horizontal lines intoellipses that run from side to side, or from the center of the diagram outward. Vertical lines become radial lines that project from the center of the circle toward the outer edges. Mathematically, the shading mask protractor can be represented with three line types, namely, concentric circles, radial lines and two series of ellipses. The concentric circles represent the altitude of a point on a hemisphere above the horizon, the radial lines represent the edge of vertical surface with respect to its off-south azimuth, and the two series of ellipses represent horizontal lines which run parallel or perpendicular to the plane of the window.

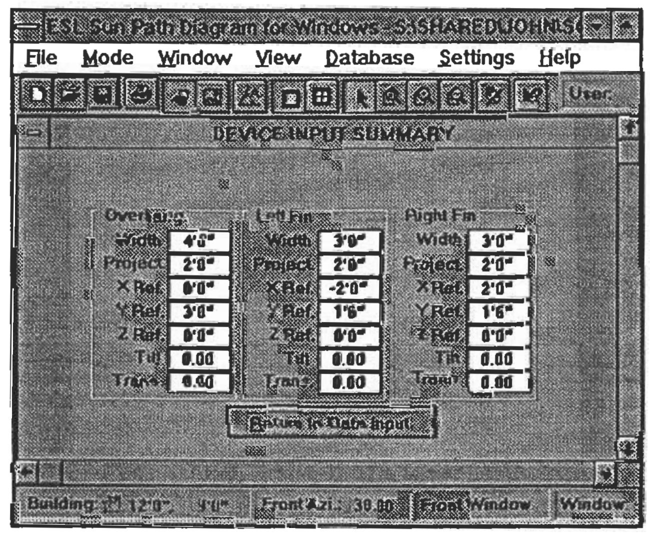

FIGURE 3a: Data Input Summary Screen. This figure shows the data input screen where all pertinent data for the currently displayed facade are shown. The data shown represent the dimensions of the horizontal shade and left and right fins shown in Figure 1.

The second set of hemisperical coordinates represents the sun's path across the sky dome for a given latitude. Such a path can be described with two additional sets of curves. The first set of curves represent seven traces of the sun across the sky from sunrise to sunset [3]. The second set of curves represent the location of the sun at the same time-

[3] One trace each for December and June, and one trace for each pair of months between December and June, specifically;

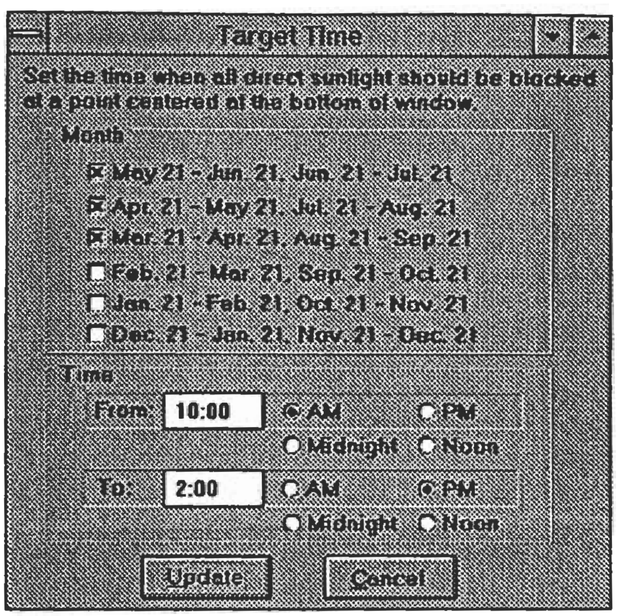

FIGURE 3b: Solar Target Time. This figure shows the data input screen for the time of day, and time of year that shading is to be provided.

of-day throughout the year[4]. The curves that represent the sun's path can be described by selectively plotting the well-known solar equations that describe the sun's zenith angle and the off-south solar azimuth angle (Duffie and Beckman 1991; Kreith and Kreider 1978). Additional details about the mathematics and algorithms that can be used to construct the shading mask protractor and sunpath diagram can be found in the references by McWatters and Haberl (1994a; 1994b; 1995).

Figure 1 shows the opening screen for the solar shading analysis program. The combined sunpath diagram and shading mask protractor can be seen in the upper right quadrant. All data entry is made in the "data input" screen to its left. Modifications to the shading devices are shown on the various views of the building and window in the lower screens. The effect of the shading is shown on the combined sunpath diagram and shading mask protractor shown in Figure 2 which illustrates the shading on a window that is 4 feet in width by 3 feet in height facing 30 degrees east of south at a northern latitude of 30.3 degrees [5]. The shading devices, shown in Figure 1, consist of an overhang accompanied by left and right fins with the dimensions as shown in Figure 3a. The coordinates for the windows are measured from a point centered at the bottom of the window. The X, Y, Z reference points locate a point in the center of each shading plane. The results of the shading analysis are shown in Figure 2.The time that has been targeted for shading entered into the data entry screen shown in Figure 3b.

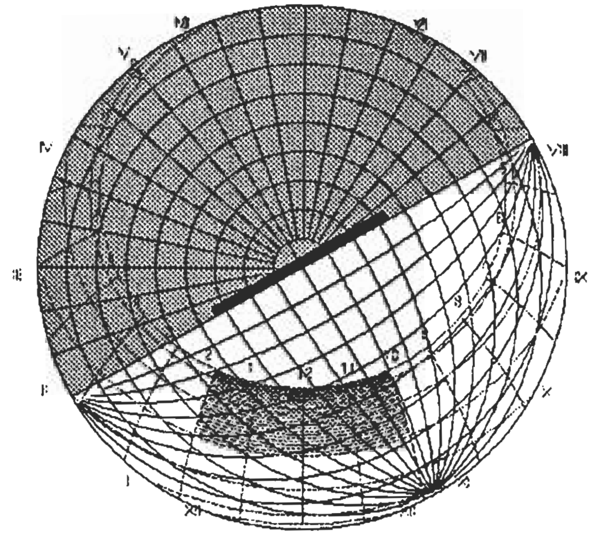

FIGURE 4: Sunpath Diagram and Shading Mask Protractor for 65 Degrees North Latitude. This combined diagram shows the sunpath diagram and shading mask protractor for a vertical surface facing 30 degrees east of south.

The solar shading analysis program can be used to represent any north or south latitude, including latitudes at or above the arctic circle, such as the 65 degree north latitude shown in Figure 4, or latitudes in the southern hemisphere, such as the 30 degree south latitude shown in

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November-January, October-February, September-March, August-April, and July-May. The traces for December and June represent winter and summer solstice.

[4] This assumes solar time.

[5] The shading indicated in Figure 2 is color coded with a separate colors to match to match the horizontal, left and right fins. Separate shading is indicated for that area of the shading mask protractor that represents the area shaded by the vertical wall. The width of the window is also indicated on the diagram as bold line in the center of the shading mask. The sun's path has been darkened from 10:00 a.m. until 2:00 p.m. from March 21stthrough September 21st (i.e., the summer cooling season).

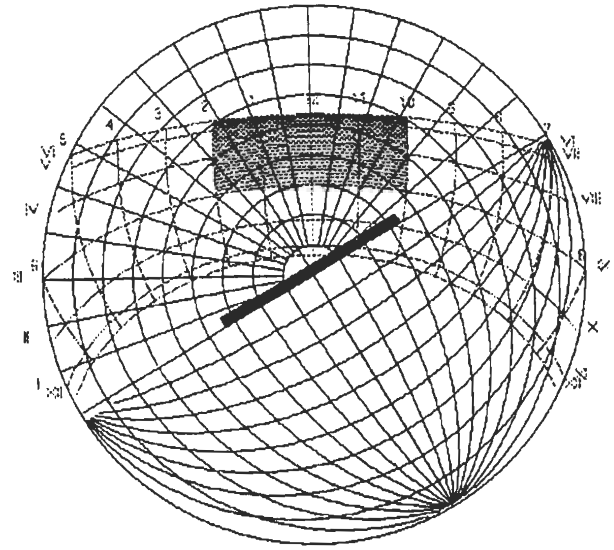

FIGURE 5: Sunpath Diagram and Shading Mask Protractor for 30 Degrees South Latitude. This combined diagram shows the sunpath diagram and shading mask protractor for a vertical surface facing 30 degrees east of south.

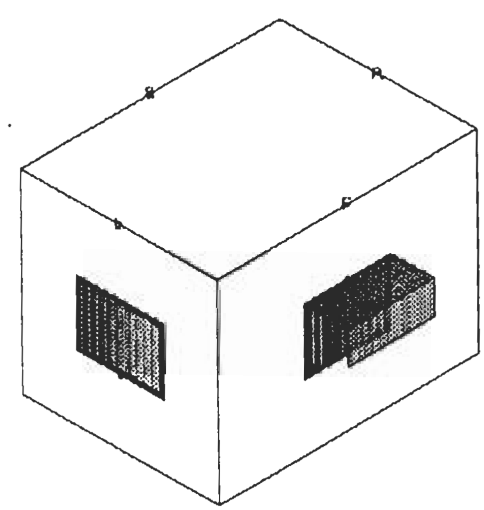

FIGURE 6: Simplified Shading Device for Partial Shading of the Sun. This figure shows a simplified shading device for a window in a facade facing 30 degrees east of south that shades the sun during the majority of the mid-day hours during the cooling season.

Figure 5. In both cases, the shading mask protractor is shown for a facade facing 30 degrees east of south. A target shading time of 10:00 a.m. until 2:00 p.m. is indicated on the sun's path for the period from March 21st through September 21st (i.e., the cooling season in the northern latitude). The effect of the shading has been removed to facilitate easier viewing of the sun's path. Obviously, summer shading in the southern hemisphere would need to be provided for a north, east or west facing facade.

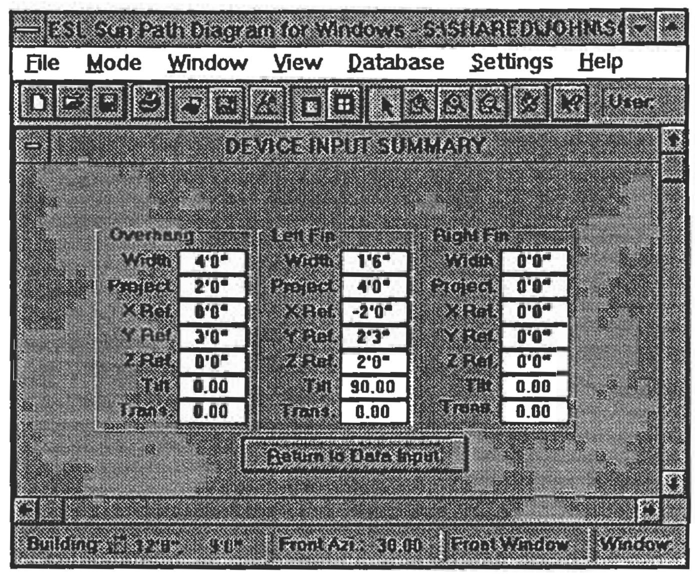

FIGURE 7: Data Input Summary for the Partial Shading Device. The dimensions of the partial shading device are shown for a horizontal fin covering the 4 foot width of the window and projecting out 2 feet. The left fin has been placed in front of the window to serve as a skirt immediately below the horizontal shade and measures 2 feet by 4 feet.

COMPARING THE RESULTS OF THE CURRENT PROGRAM AGAINST TRADITIONALLY PUBLISHED ANALYSIS.

In Figure 6 a simplified shading device is shown for a window in a facade facing 30 degrees east of south. The dimensions of the shading device are shown in Figure 7 and the contributions of the horizontal and front shades [6] are shown in Figure 8. The targeted shading time remains at 10:00 a.m. to 2:00 p.m. from March 21st through September 21st. By contrast, the shading for a similarly dimensioned device published in the

[6] In Figure 7 and 8 the front shade is actually the left fin that has been rotated 90 degrees, re-sized and moved to a position directly below the horizontal shade.

Architectural Graphics Standard [7] is shown in Figure 9. Clearly, the lower edge of the previous analysis agrees with the current analysis.

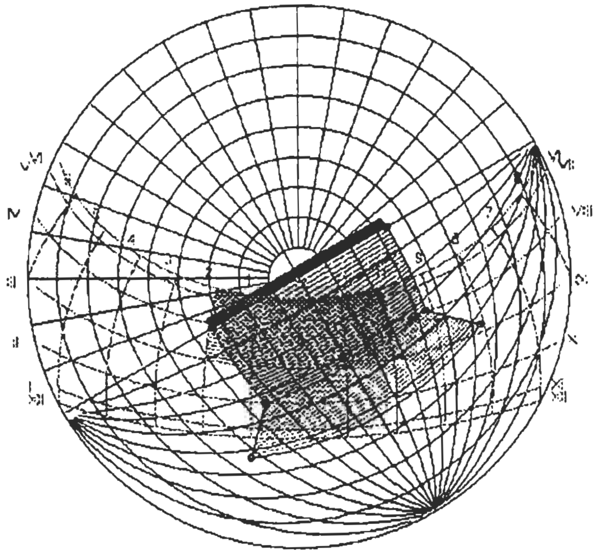

FIGURE 8: Shading Analysis for the Partial Shading Device. The individual contributions from the horizontal, left and front shades are shown in this figure. The width of the window is also indicated as the bold line in the middle of the shading mask protractor.

However, the previous analysis would lead one to believe that the shading available from such a device incorrectly vanishes into the distance along the sides of the facade [8]. The current analysis (Figure 8) shows the horizon shading profile stopping at the edges of the window [9] and projecting normal to the plane of the window until it meets the vertical front skirt that extends downward. The shrimp-tail appearance of the combined shape of the horizontal shade and skirt can be confirmed by tracing the similar edges shown in Figure 2.

[7] Ramsey and Sleeper (1994), p. 733

[8] The shading profile shown is from an equivalently shaped overhang that projects fifteen feet to the sides of the center of the window. An infinite shading device would have extended the shaded region to the horizon.

[9] This is also one of the new features of the current program. Previously, the size of the window was never shown on the shading mask protractor. We have found that it is useful to show the width of the window on the shading mask protractor because it helps to analyze the size and position of the shading devices.

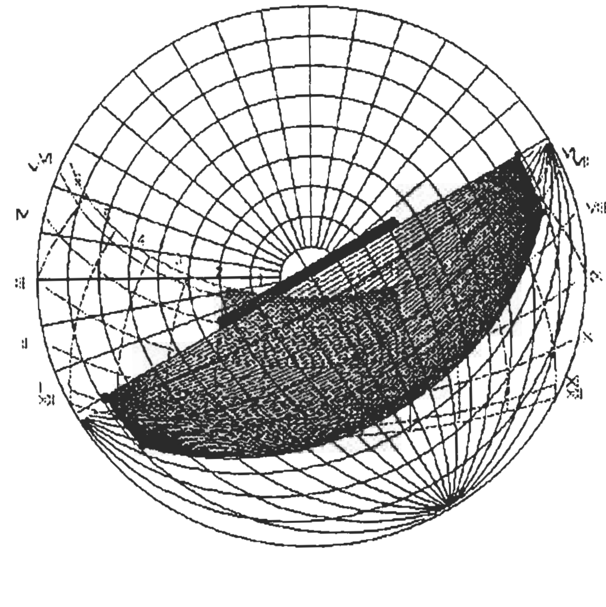

FIGURE 9: Previously Published Analysis for the Partial Shading Device. This figure shows the previously published shading analysis for a similarly shaped shading device as it appeared in the Architectural Graphic Standards (Ramsey and Sleeper 1994, p. 733).

SUMMARY

This paper has presented a new MS-Windows-based educational software package that has been developed to fast-track the learning and use of the sunpath diagram and shading mask protractor which is based on previously published equations for plotting the sunpath diagram and shading mask protractor. Examples were provided that demonstrated some basic configurations of shading devices that are often misrepresented in the standard literature.

The use of the program at the university has proven to be extremely beneficial in conveying to the students the usefulness of the shading mask protractor and sunpath diagram. Future work includes: i) the development of an external shape shading functions that will allow one to analyze the effect of multiple objects placed in front of the window at various orientations; and ii) the addition of the ability to project hourly measured solar data upon the sunpath diagram modify according the to incidence angle of the plane of the window, and iii) the addition of a thermal analysis to predict the heat gain through the window.

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