CALCULATING VARIATIONS IN THE DISTRIBUTION OF INSOLATION OVER BUILDING SURFACES

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This paper presents a methodology for the calculation and display of distributed cumulative incident solar radiation (insolation) over any number of building surfaces for any date/time range. It also describes how the methodology can be extended to the design of external shading devices, allowing the designer to interactively generate shading shapes by simply selecting a surface insolation level. Examples of the use of this method on building projects are described as well as some of the benefits and limitations of the method.

Introduction

In many climates incident solar radiation (insolation) on the external surfaces of buildings is a major source of internal heat gain. This can occur through both glazing and the opaque fabric if it is not adequately insulated. Traditional glazing and shading strategies tend to treat each façade homogenously, assuming the entire surface to be similarly exposed. However this is not always the case, especially with curvilinear façade systems and more complex building shapes where small angular differences and self shading can result in significant variation. Similarly, complex site overshadowing by surrounding buildings in dense urban environments can also create large differentials in the distribution of insolation over each façade.

If this information is available to the designer sufficiently early in the project it can be an important influence on both the building form and its exposed fabric. Knowing which parts of a surface are subject to high levels of solar stress, and which aren't, can yield significant economies in the application of appropriate façade systems, allowing the designer to specifically target problem areas. In colder climates the aim is more often to make best use of a limited resource, both for utilising direct gain and for optimising the location of photovoltaics and solar collectors.

A method for the calculation and display of surface insolation has been developed and implemented within the ECOTECT software. The concept on which the methodology is based has also been extended - and in some ways reversed - to provide a means for the interactive and numerical design of shading devices.

Surface Insolation

There are many ways to calculate cumulative insolation on a surface. However, they all involve two processes; the first to deal with diffuse radiation from the entire sky dome and the second to deal with direct radiation from the Sun. The methodology presented here is based on the use of calculated shading masks, which the author advocates over other systems for a number of practical reasons outlined below.

Shading Masks

A shading mask is simply a mechanism for calculating and storing those parts of the sky dome that are visible from a particular point. This information can then be plotted on a sun-path diagram to show when in the year the point is in shade or not. Whilst this diagram can be generated by projecting shadowing surfaces back towards the point and storing a series of transformed polygons (as shown in Figure 1 - Left), it is more useful for numerical analysis to divide the sky dome into many angular segments and store an array of shading values (as shown in Figure 1 - Right).

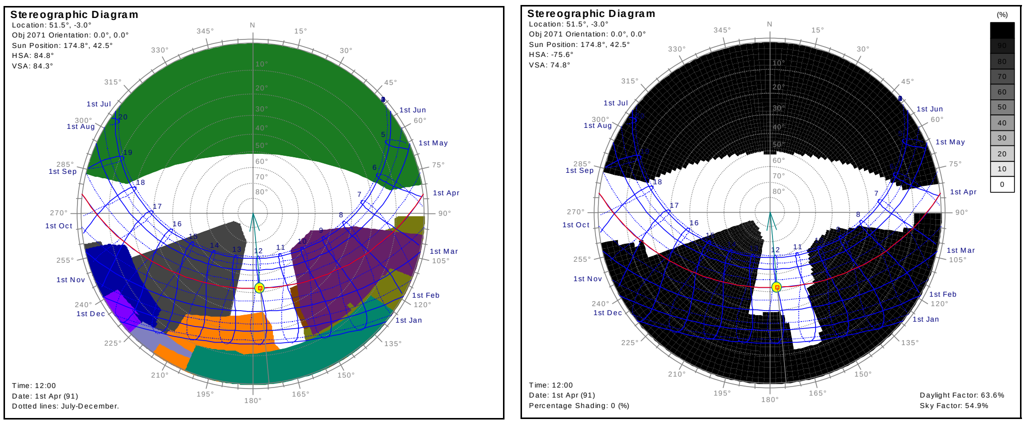

Figure 1 – Two example shading masks for a shadowed point – on the left individual shading polygons transformed onto the sun-path diagram and on the right the sky dome divided into an array of angular segments, each either shading or not shading.

The benefit of using the array approach is that each cell can store quite complex data. As shown above, the shading mask for a point is hard edged - it is either in shade at a particular time or not. The shading mask for a planar surface however is usually soft-edged as it may only be partially in shade at a particular time. One of the simplest ways of determining the partial shading of a surface is to sample it as a series of distributed points and average the results into a single mask. This way each array cell can store fractional obstruction values, shading percentages or even cumulative radiation.

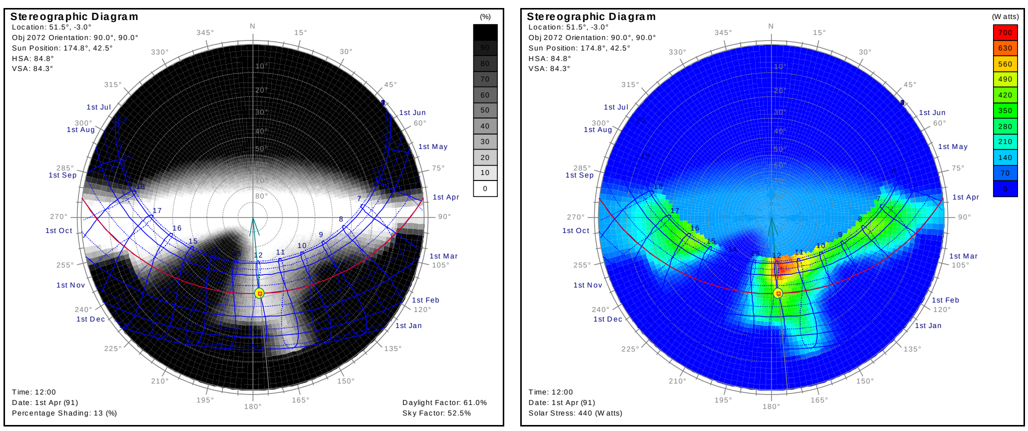

Figure 2 – Example shading masks for surfaces showing percentage shading (left) and cumulative annual solar radiation from each sky segment.

It is also possible to accommodate the effects of transparent and reflective surfaces within the mask. Basic ray-tracing techniques can be used to continue tracing through any number of transparent surfaces, whilst reflected rays can be spawned to determine which other part of the sky forms the reflected image, even after multiple reflections. Given a particular radiant distribution for the sky, the insolation value is simply the sum of the radiant energy in each segment multiplied by the fraction transmitted and/or reflected.

When using hourly weather data the exact sky distribution is usually not known, however the individual instantaneous direct and diffuse components are. If a standard sun-less sky distribution is assumed, then a single-value diffuse sky factor can be pre-calculated from the mask and applied to the diffuse component at each time interval. The direct component can then be determined by transposing the size and position of the solar orb into the array at each time interval and moderating the direct component by the transmitted and reflected value for each affected cell.

One major benefit of pre-calculating and storing shading masks for each surface is that they need only be regenerated when the physical geometry or materiality of the model changes. Thus it is possible to analyse many different time periods and even changes in orientation using the same stored masks.

Variations in Surface Insolation

To view the variation in insolation levels over large surfaces, many shading masks can be generated and cached at distributed points across the surface. This is usually done using a regular grid, however this is not essential. Any number of sample points can be used, depending on system memory and available calculation time, with levels of bounded pseudo-randomness introduced if required to jitter the relative position of each point. The results can then be visualised over each surface within the 3D model.

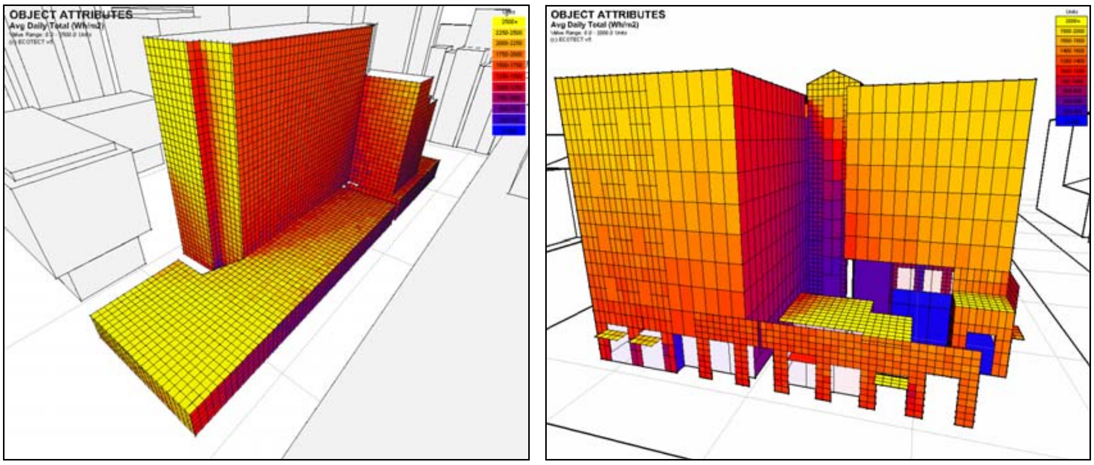

Figure 3 – Examples of incident solar radiation (insolation) mapped over building surfaces on sites in London (left) and Athens (right).

The examples in Figure 3 above show that the methodology also accounts for self shading and allows the designer to concentrate surface subdivisions in specific areas of interest. An example in Figure 4 below also shows that the method is equally applicable to the analysis of areas of open space between buildings.

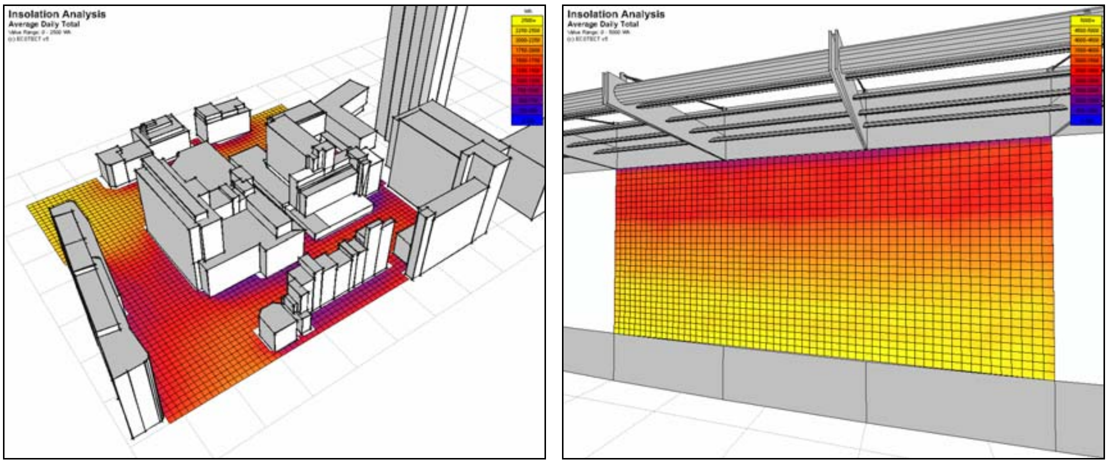

Figure 4 – An example of insolation over areas of open space (left) and the use of the method to assess the relative effectiveness of a detailed shading device (right).

A further application of the same methodology is to examine the spatial effectiveness of detailed shading devices on the window surfaces they are intended to shade (Figure 4 – Right). This information can be used to objectively assess and optimise the design of the shading device or, alternatively, to optimise the design of the window itself. As an example, the solar distribution in Figure 4 could be used to apply different types of solar control glass at different heights within the window, allowing clear glazing at the top to slightly increase localised daylight availability.

Shading Design

The basic concept of projecting insolation onto a window can also be reversed, to project the window back towards the Sun onto each shading surface. This technique builds on earlier ray-tracing methods developed by the author (Marsh, 1997 & 2003) as well as work by Kaftan in the development of his Cellular Method (Kaftan 2001). The Cellular Method applies a similar technique to a shaded building zone, extending it with considerations for internal comfort and comparative heating and cooling costs.

To illustrate the basic process, consider the simple example shown in Figure 5 below. The selected window is projected onto a grid plane slightly above the window head at set time intervals throughout the analysis period.

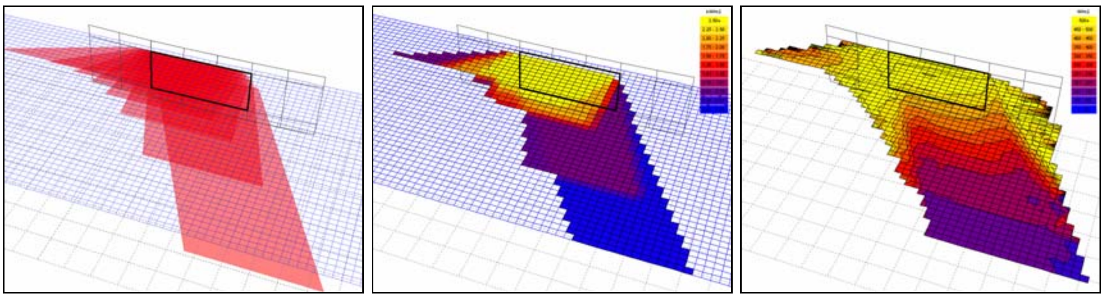

Figure 5 – The image on the left shows a rectangular window projected onto a horizontal shading grid at set time intervals. The direct solar radiation at each time is then added to each shading cell. The centre image shows a single-day result whilst the image on the right shows the daily average taken over a whole year.

If the instantaneous direct solar radiation at each time interval is accumulated on the shading surface, then the total value at each point can be used as an indicator of the relative importance of the space immediately around that point to the overall shading potential.

Three important values can be derived from such an analysis for each grid point;

- the total cumulative result over the whole analysis period,
- peak instantaneous radiation and
- daily averaged values.

Contours of each of these values across the grid can then be used to effectively 'dial' up the shape of a shading device based on either a maximum instantaneous solar gain or, in the case of cumulative values, a total kWh load on each window. Figure 6 clearly demonstrates this process. The image on the left shows the cells required to completely shade the window over the analysis period. The centre image shows those cells required to limit total solar gains to 5 kWh whilst the image to the right shows a 25 kWh limit. Points whose values are below the specified cut-off are eliminated from the display.

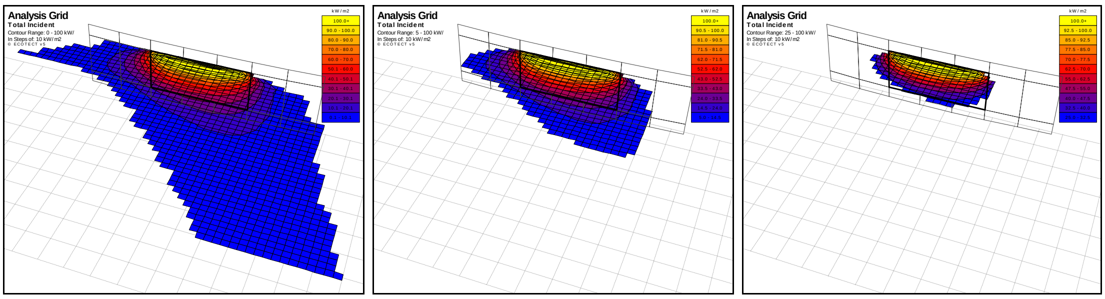

Figure 6 – A demonstration of 'dialing up' the shape of a shading device based in this case on total solar gains of 1, 5 and 25 kWh on the window, but just as easily on peak instantaneous gains.

This can obviously be extended to shading devices of any shape and orientation relative to the window, or even for multiple shaded surfaces. Development of a method for generating 3D shading volumes using the same technique is currently being undertaken.

Solar Access

This same process can also be useful in situations where solar radiation is required. In the case of soccer stadia in the UK, solar radiation on the playing surface during winter is very important for turf recovery between matches. Pitch replacement is a significant cost for many clubs, so maximising solar availability at the right times of the year to prolong turf life is critical in the architectural design of the stadium.

If a grid is placed over the entire roof area of the stadium, and the whole playing surface projected back onto it throughout winter, it is possible to map the most significant areas where obstruction should be minimised. In the example illustrated below, the resulting data was then clipped to the proposed roof shape to find the most effective location for roof glazing panels.

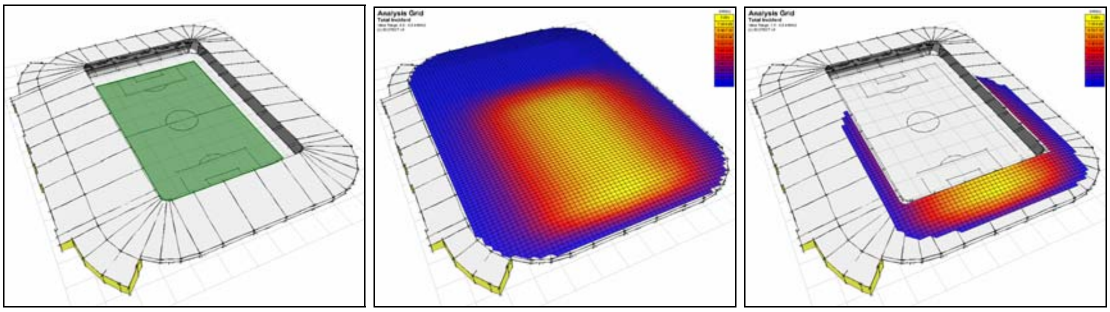

Figure 7 – The optimum location of roof glazing panels can be quickly determined using projections of the playing surface onto the roof area over Winter.

Conclusion

The method presented here provides the building designer with a range of information not normally available during the design process. At its most basic level, simply visualising variations in solar radiation across surfaces can be a useful decision-making tool at concept stage. As the design develops, applications of this information range from overall large-scale overshadowing effects to the detailed performance analysis of individual shading devices. As has been shown, extensions to the method also allow for a performance-driven approach to the design of shading devices and for the optimisation of solar access.

References

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