Non-Uniformity in Incident Solar Radiation over the Facades of High Rise Buildings

Dr Andrew Marsh[1]

[1]Welsh School of Architecture and Square One research

ABSTRACT: In a dense urban environment, complex overshadowing causes significant variation in the distribution of incident solar radiation (insolation) over the facades of most buildings. However surface treatments, glazing selection and shading designs tend to be uniformly applied. This paper argues that an appropriate consideration of surface insolation can lead to significant economies, especially in complex projects where there is self-shading.

A technique is presented for calculating and displaying distributed cumulative insolation over the facades of building models in overshadowed sites. This clearly shows the distribution of solar stresses on each façade at different times of the day and year. Such information can then be used by the designer to more appropriately apply glazing or optimise the use of solar control glass and shading devices in different areas.

A number of examples are used to illustrate the application of these techniques and where potential savings in design costs can be made. The paper also shows how these techniques can be used to assess the potential for building-integrated photovoltaics, assist in the landscape planning of outdoor spaces and optimise the location of solar collectors.

Conference Topic: 2 Design strategies and tools / Sustainability and high-rise buildings
Keywords: solar radiation, facades

INTRODUCTION

Taking maximum advantage of available daylight and solar radiation is an important part of modern building design, especially in view of legislative requirements to conserve energy and reduce carbon emissions. However in an increasingly dense urban environment this is becoming more difficult due to significant overshadowing effects.

There are two aspects of overshadowing to consider. The first is the impact that the new building is likely to have on the solar access and right-to-light of existing windows in adjacent buildings. In most cities this is covered by its own set of regulations and very specific requirements. The second is the effect of those same adjacent buildings on the solar access and daylight availability on windows within the new building.

For many high-rise developments this is likely to vary quite significantly, with lower floors having greatly reduced levels compared to the upper floors. In such cases it is likely that, within the same façade, some windows will require significant solar control whilst others will battle to receive enough indirect light to comply with even the most basic daylighting requirements. However, most glazing and shading strategies tend to treat each façade homogenously, assuming the entire surface to be similarly exposed.

This paper therefore presents a method for accurately calculating and visualising the degree of non-uniformity in incident solar radiation (insolation) and daylight availability over complex facades. Such information provides the designer with opportunities for both innovation and significant economies through the optimisation of solar control strategies and a more appropriate application of glazing systems.

2. BACKGROUND

2.1 The Need for New Methods

Lighting simulation tools such as Radiance[1] have long been able to determine the distribution of sky illumination over surfaces, using radiant exchange algorithms to quite accurately model even highly diffuse conditions. This allows the generation of illuminance levels mapped over building surfaces, an example of which is shown in Figure 1 below.

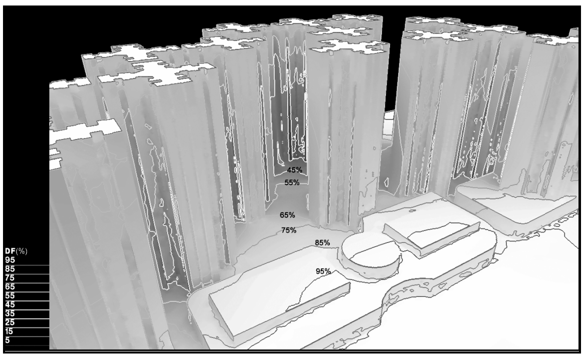

Figure 1: The mapping of percentage illuminance based on static environmental lighting conditions.

Such images are important for the estimation of daylight availability and can clearly show significant variation in some cases. However they show results for only a single moment in time - if lighting conditions change, then the entire map has to be recalculated. As a result, surface illuminance calculations are usually based on representative conditions such as a standardised CIE Overcast Sky or an Average Sky.

However for insolation analysis, the interest is more on average, peak and cumulative values taken over long time periods. This requires that the calculation be dynamic and able to handle a whole set of changing conditions. This is important as most weather stations collect hourly values for direct and diffuse solar radiation, making possible a very accurate and site-specific analysis.

2.2 The Use of Shading Masks

As the geometry of surrounding buildings does not change, the annual overshadowing of each building object can be pre-calculated in the form of a shading mask. These simply represent the area of sky dome that is ‘visible’ from each surface. Obviously the higher a window is relative to its surrounding objects the greater the area of unobstructed sky, as shown in Figure 2 below.

This area of unobstructed sky is known as the Solar Envelope and is unique to each object. Once calculated, different sky conditions can be mapped into this visible area to very quickly determine the effect on any object in the model. For example, mapping an Overcast Sky allows for the direct derivation of daylight factors and vertical sky components by simply calculating the percentage of illuminance visible. As the position of the Sun throughout the year is known, illustrated by the overlaid sun-path lines in Figure 2, it is also possible to map the effects of a sunny sky by apportioning the amount of direct sunlight to a very small area of the sky corresponding to the current Sun position.

Using this technique, hourly direct and diffuse solar radiation values from local weather data can be overlaid on the mask. The direct component is assigned a position and then moderated by the percentage shading in the mask at that point. The contribution of the diffuse component depends on the overall percentage of sky that is visible to each object. To model changes over time, these values are simply summated within the mask over the selected period.

Figure 3 shows such a mapping over the entire year for the same windows shown in Figure 2, using London weather data for 1984.

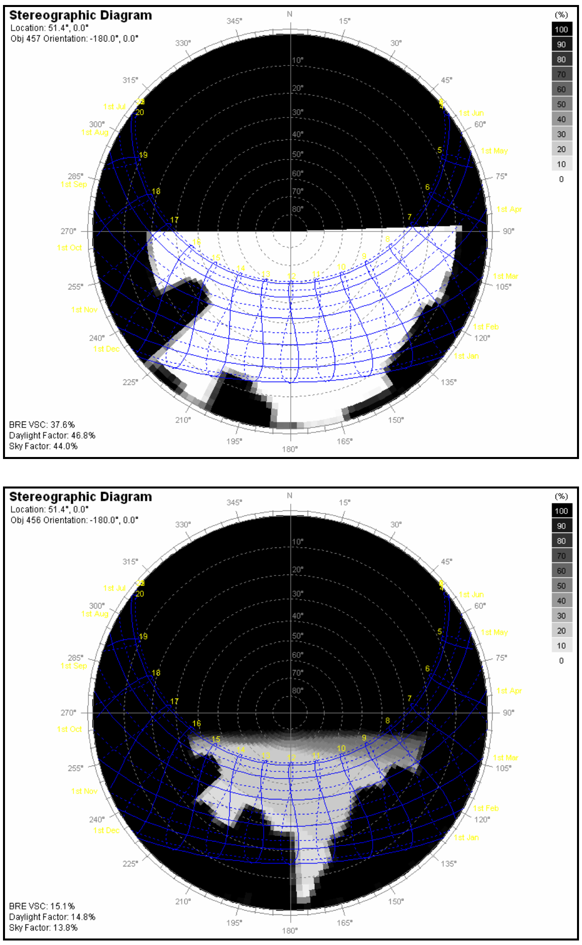

Figure 2: The shading masks of two windows showing the area of unobstructed sky visible from an upper floor (top) and lower floor (bottom) location.

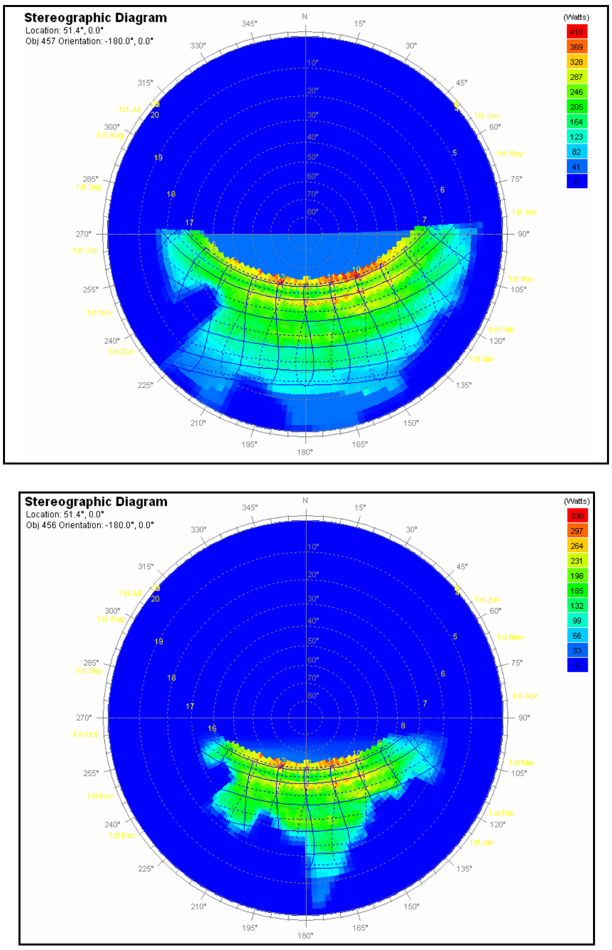

Figure 3: The same windows as Fig. 2 but with annual hourly direct and diffuse solar radiation values mapped and summated over the sky dome.

2.3 Mapping Diffuse Radiation

Whilst it is relatively simple to locate direct radiation values along the sun-path, diffuse radiation is actually distributed over the entire sky dome. Moreover, work by Roy, et.al.[2] clearly shows that under different sky conditions this distribution can be very complex. For example, in an idealised overcast sky more light comes from a point at the zenith than from a point at the horizon (three times as much). For a clear sky the corona around the Sun dominates the distribution. Figure 4 shows some examples of this variation using sky illuminance, which is closely linked to radiant distribution.

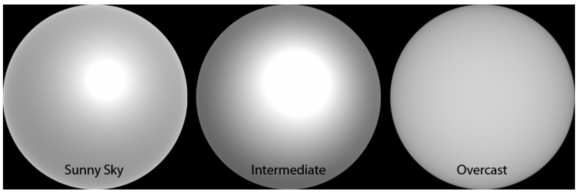

Figure 4: The variation in illuminance distribution over the sky dome under different sky conditions.

Thus, even though two surfaces may have the same percentage of visible sky, if the two solar apertures expose different areas of that sky, then the insolation values in each surface will be different. It is important to note that the shading mask method can accommodate these variations, even allowing for dynamic interpolation between conditions.

However, usually there is insufficient recorded information on which to base such interpolations. For example, most weather stations record only hourly direct and diffuse radiation as well as the amount of cloud cover. In cases of partial cloudiness, without an image of the actual sky distribution, there is no way of telling which parts of the sky dome were clear and which cloudy. Thus, whilst the method can accommodate complex distribution patterns, without additional detailed information, for clarity this work has assumed a uniform distribution of diffuse radiation across the sky dome.

3. APPLICATIONS

Whilst there are a wide range of applications for this methodology, this paper focuses mainly on the potential for decision-making feedback during the planning and building design processes. The most immediately obvious application is the determination of shading requirements over building façades which, when looked at from a different perspective, also includes locating surfaces with the greatest potential for photovoltaics and solar collection. Less obvious applications include the ability to consider solar-induced radiant temperature effects and the selection of appropriate vegetation within exposed spaces.

3.1 Outdoor Solar Access

One area of increasing interest in urban planning is the availability of both daylight and solar radiation in outdoor open spaces. Many inner-city spaces where the public can enjoy direct sunlight are coming under intense pressure from new developments. Whilst a simple shadow analysis can be used to show when shading occurs at different positions within a space, a cumulative radiation analysis can more clearly show seasonal and comparative effects.

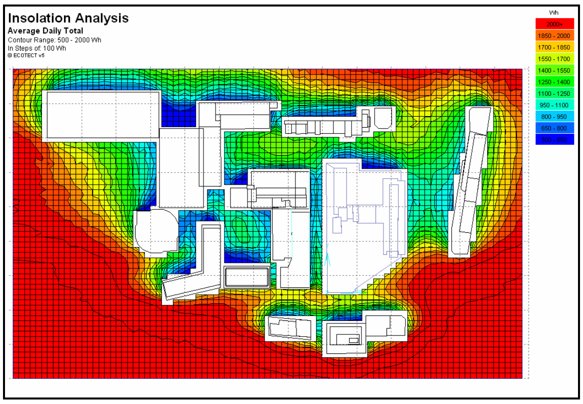

Figure 5: An example of variation in available annual solar radiation in the open spaces around buildings.

Information such as that shown in Figure 5 is important not only in designing the layout of each space, but can greatly assist in the planning of landscape and vegetation. Maps of seasonal solar access can be used to best position planting beds as well as selecting the most appropriate species for each bed based on their sunlight requirements.

One rather topical application of this idea is the calculation of solar radiation over the grassed playing surfaces in sports stadium. Adequate sunlight is vital for grass growth and reducing recovery time of the turf between matches. A comparison of solar gains over the pitch is important if the roof design is to allow sufficient solar access at the equator-end of the pitch. Figure 6 shows just how variant this can be. with average annual radiation values at one end less than a fifth of those at the other.

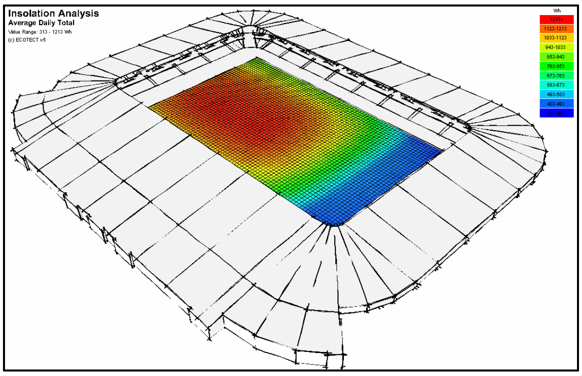

Figure 6: Annual insolation falling on the grass playing surface of a sports facility, showing a clear reduction towards the southern end.

An extension of this application is to consider the distribution of comfort within a semi-outdoor space. Whilst direct Sun is a major factor in human comfort, so too are the radiant emissions of surrounding surfaces - especially if they have been heated by exposure to the Sun. If surface gains are already known, then it is relatively simple to combine them with material absorption and emission properties to calculate the mean radiant temperature at points within the enclosure. This information can be used once again to position vegetation to best shield against hot surfaces as leaves and plant materials do not heat up as much when exposed to solar radiation and have very low surface emissivities. Figure 7 shows how radiation values can be mapped over all surfaces surrounding an enclosure.

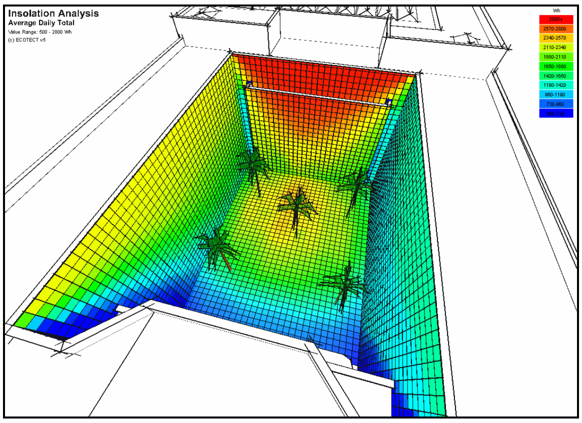

Figure 7: Using surface insolation to consider mean radiant temperature effects within an enclosed space.

3.2 Façade Shading Requirements

Mapping insolation values over building surfaces can also be used to clearly illustrate relative shading requirements at different locations within each façade. This information can be used to choose appropriate strategies in both the design of shading devices and the controlled application of solar control glazing to each aperture. It can also be used to alert the designer to those parts of the façade where more care must be taken to ensure adequate daylight admission. Figure 8 shows just how much insolation values can vary on an overshadowed façade.

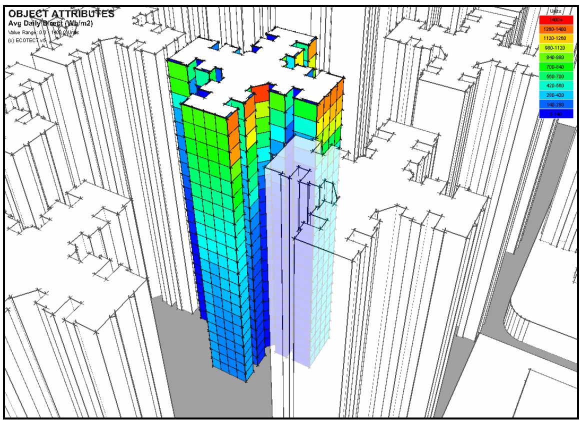

Figure 8: In dense urban environments, solar access can vary enormously within only a few floors at the top of a development.

The objective quantification of this variation can lead to significant savings. As stated previously, these are mainly possible through a more tailored approach to shading design and ensuring that expensive spectrally selective glass is used only where actually needed.

There is always concern amongst designers about the degree to which a design can reliably depend upon the shading of surrounding buildings. As the events of September the 11th in New York demonstrated, the skyline of a city can change almost overnight. This argument is often put forward to justify the homogeneous application of shading strategies over entire facades. There is some merit in this, however when a building is part of a large development complex or involves significant self shading, as shown in Figure 9 below, then the potential gains can be reliably achieved.

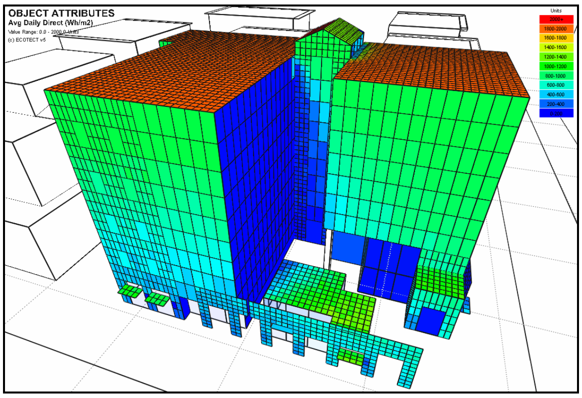

Figure 9: Variations in insolation due to self shading.

3.3 Solar Collection Opportunities

With the pressures of international carbon reduction agreements, many governments actively encourage the adoption of renewable energy sources in buildings, the most common of which are solar water heating systems and photovoltaics. On a complex site, cumulative radiation mapping clearly shows those surfaces with the greatest solar collection potential. With the right choice of period over which the values are calculated, the results can even be optimised for a particular season or set of environmental conditions.

3.4 Shading Effectiveness

Once a shading strategy has been developed, shading masks and cumulative insolation analysis can be used at any scale to help refine it and objectively assess its effectiveness. This can be done even at individual window level.

Figure 10 shows an example of this for a Brise Soleil shading system. Over the course of a year, the analysis clearly shows significant variation in peak solar gains over the surface of the window. Thus, with some careful design, it would be possible for example to segment the window horizontally using darkened or tinted glazing along the bottom where the gains are highest and clear glass at the top. This has the potential benefit of reducing overall costs and increasing diffuse light entry into the space.

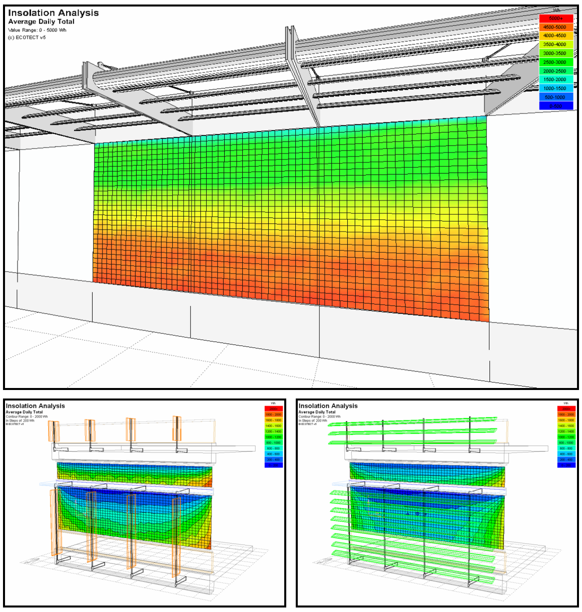

Figure 10: Examples of the use of cumulative insolation to model the effectiveness of detailed shading devices.

This method can also be used to objectively compare the potential benefits of different shading systems when installed on a building. As the insolation on each segment of a window can be determined, this can be instantly converted into solar gains and therefore potential energy and cost savings due to reductions in ongoing operation and peak duty cycles of the buildings mechanical systems. Figure 11 shows such a comparison of the in-situ effects of three alternate shading solutions on direct solar gains through a complex set of curved windows.

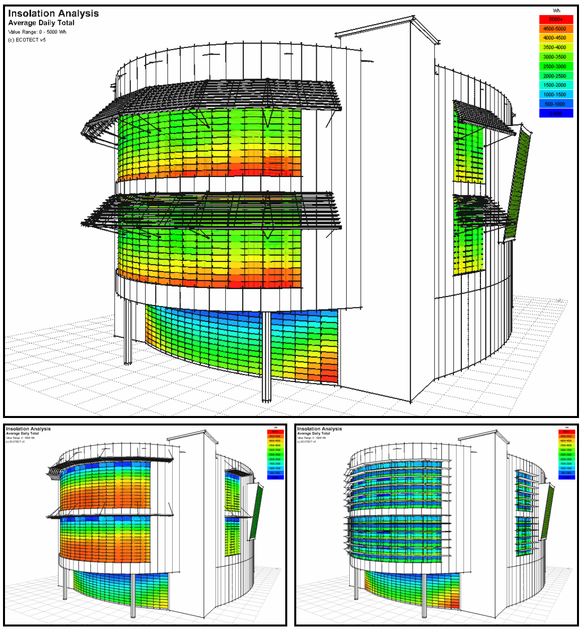

Figure 11: An example of the in-situ analysis of shading device effectiveness over curved windows.

Similarly, by analysing shading effects over different seasons, it is possible to optimise the shading system to reduce gains in Summer whilst actually allowing them in Winter to offset space heating costs.

CONCLUSION

This paper has outlined a method of using shading masks and recorded hourly solar radiation data to analyse and visualise variations in incident solar radiation over building surfaces. It has shown how this method has a range of other applications, from landscape planning to the detailed assessment of specific shading solutions, and can be used within the building design process to optimise the use of shading and solar control glazings.

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