

# Examples of Glare Remediation Techniques

## Four buildings

MARC SCHILER

School of Architecture, University of Southern California, Los Angeles, CA 90089-0291

*ABSTRACT: Several techniques have been developed to locate and evaluate glare in buildings. Some of those techniques have been applied to finding cases of significant or extreme exterior glare. These techniques are evaluated and none is yet perfect. There are also different categories of solutions to mitigate glare in the urban microclimate. Including surface treatments, additional surface articulation, freestanding shielding and landscape elements. Several case studies are examined, with a variety of solutions depending on individual conditions. These techniques are compared in relation to each other and depending on the particular cases in which they were employed.*

*Keywords: Gehry, glare, Walt Disney Concert Hall, LAUSD Central High School for the Arts, Princeton University Lewis Science Library*

### INTRODUCTION

Glare (visual and thermal) is a significant problem in warm and hot climates, both inside buildings and in the surrounding microenvironment. Architectural materials have been increasingly sophisticated at rejecting or even selectively filtering radiant gain, but the by-product has sometimes been an increase in the negative impact on surrounding buildings, traffic and outdoor spaces. This difficulty may be referred to as *thermal* and *visual glare*. See Fig. 1. It is true, even in cool and cold climates, especially in urban situations. Such impacts have been documented in previous papers. [1, 2, 3] Different methods for identifying glare have been proposed and applied and evaluated, with varying success.

### DEFINING AND MEASURING GLARE

The word “glare” is used to describe a surprisingly broad range of phenomena. It is useful to clarify what is meant in different applications and how to measure each of those phenomena, before trying to correct them. The most obvious differentiation is the difference between thermal glare and visual glare.

Thermal glare is the concentration of radiant energy which causes unwanted heat gain. It is not necessarily visible, but can be quite significant.

Visual glare is somewhat more complex. Traditional definitions of visual glare have related to the effect of the glare, rather than the source or process. It would be useful to address the source and the impact separately.



Figure 0 : Glare Reflected onto Neighbor

Glare has traditionally been divided into two categories: disability glare and discomfort glare, with the later addition or separation of veiling reflections. Hopkinson noted that “Disability glare can actually reduce the ability to see; when this happens we say that there is ‘disability glare’.” But then he noted that “‘Discomfort glare’ can be present without any degree of disability.... Little or no disability may be caused, but the degree of discomfort may be most marked.” [4] This implied a progression of levels of glare, with discomfort being the first level and disability being the second. There was not much discussion of greater levels, such as damage to the eye or the kind of glare which occurs in outdoor environments. Veiling reflection was not mentioned at all. Reflections were only discussed in the context of discomfort glare. A reflection which hid information would be considered a subset of disability glare.

These categories deal with the results of glare. But none of these categories deals with the *cause* or mechanism of the glare. It is useful to address three causes or mechanisms of glare: **absolute** glare, **relative** glare and **informational** glare. Absolute glare occurs when there is a (source of) luminance in the field of view which is sufficient to cause damage to the eye, no matter what the relative background level. Relative glare occurs when the eye adapts to the background luminance level in a field of view and the contrast between a specific luminance in the field and the background exceeds some ratio. Most work has been done on relative glare. Informational glare occurs when the signal-to-noise ratio makes the desired information unavailable. Light reflecting off of a computer screen is annoying because the information on the screen is lost even if the reflected luminance does not qualify under the other two categories. This paper discusses examples in the built environment of the first two categories.

Hopkinson and Petherbridge developed Glare Sensation, based on the luminance of the glare source.[5] Multiple sources can be combined to form a logarithmic Glare Index. Guth developed VCP (Visual Comfort Probability) as a measure (or prediction) of what percentage of the occupants would be comfortable in a given situation. [6] Similarly, it is calculated based on the luminance of the glare source. Multiple sources are summed arithmetically to produce a Discomfort Glare rating. Einhorn developed the CIE Glare Index, (CGI) based on the luminance of a glare source (in  $\text{cd}/\text{m}^2$ ), the solid angle of the source (in steradians), the position index of the source, the direct vertical *illuminance* from all the glare sources (in lux) and the indirect vertical *illuminance* from the rest of the sources. [7] Further work has been done by utilizing digitized images of visual environments to determine luminance ranges, by Mark Rea (Capcalc) [8].

Perhaps the most useful treatment of the issue is found in the algorithms developed by Greg Ward for use with the Radiance computer program. Ward is not measuring glare, but recognizing glare conditions in a computer simulated image. He defines two steps to the process. The first is to compute the luminances within the field of view. The second is to apply a glare index to that image. In the process, he also defines an approach very similar to those used by Schiler, et al. He calls this process "thresholding." He calculates the average luminance (roughly defining the background level) and then designates any luminance greater than 7 times that value to be a possible source of glare.[9] This is very similar to the histogram approach.

There are several other measures of glare which relate to Relative Glare. Such metrics include the 10:1 ratio, the 3:1 ratio, etc. which have been previously proposed,

but which are easily misapplied. When reading this page, the observer is quite content to find at least a 100:1 difference between the luminance of the print and the luminance of the white background on which it is printed. Yet that does not, by itself, represent glare.

#### APPLICATION TO EXTERIOR GLARE

The relative glare indices were all primarily developed for interior conditions. The absolute luminances were low, unless the viewer looked directly into a lamp or was caught by a reflection of an exterior surface or source. Thus, no absolute threshold was discussed.

#### WALT DISNEY CONCERT HALL BY FRANK GEHRY

There is an urgent need, however, to find ways of measuring and dealing with exterior glare, as noted in the introduction. One such instance was the Walt Disney Concert Hall in Los Angeles by Frank Gehry. The original EIR (environmental impact report) was written for white limestone. The stainless steel which was substituted had a similar or lower reflectance, but a higher specularity, which was insufficiently considered, so the project was built without further concern. The result was disastrous, producing both visual and thermal glare. Not only was there significant overall reflectance, but concentration into focal points, as well. There was extreme visual glare and thermal glare and in some instances, elevated temperatures. Surrounding apartments reported 15 °F (8.3°C) temperature increases at various times of day. [10] There were stories of trash bins catching fire and traffic cones being melted. Experiments documented temperature increases on lightweight freestanding objects consistent with such events.

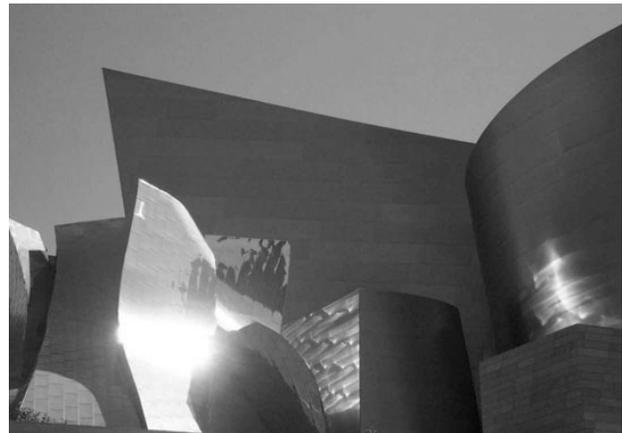


Figure 0 : Specular Reflections on Disney Concert Hall

The building was photographed at hourly intervals from all four corners and the photographs were digitized.

Histograms of the building were studied and there was a correlation between situations in which observers identified glare and histograms where the highest “spike” of luminance values were more than 3 times the median value of the “bell curve” fitted over the histograms. [11] This is consistent with experiments performed by others in controlled environments where the same pattern was noted as consistent with visual glare. [12]

In addition, it was noted that wherever an absolute luminance exceeding 12,000 cd/m<sup>2</sup> coincided with highly specular surfaces, there was the possibility of significant thermal glare. When such surfaces were concave in form, there were thermal and visual focal points which moved in conjunction with and inversely to the sun’s movement. Some of these focal points would result in significantly elevated temperatures, in addition to perceived visual glare. These points coincided with the anecdotes of elevated temperatures, etc.

Simulations of the building from critical exterior areas identified which surfaces were specular, in excess of 12,000 cd/m<sup>2</sup> and concave. These surfaces were photographed at critical times from those viewpoints and the glare was confirmed.

Several solutions were considered. It was suggested that banners surround the building. This would have been unthinkable given the iconic nature of the building. There were suggestions for landscaping. The landscaping already present was suffering from the glare and failure to thrive. Furthermore, the building was five times the height of the landscaping.

Table 1 : Specularity in Gloss Units (GU) of the Preferred Surface Treatment (Measured using Rhopoint Instrumentation Novo-Gloss Meter)

Incident Angle	Original Polished Stainless Steel	After 220 Grit Sanding
20°	749-801	34-37
60°	365-547	100-113

One of the surfaces was chosen as a test case. The specularity of that surface was reduced by simply covering it with a plastic coated cloth which was similar in reflectance to the surface, but completely non-specular in nature. The visual and thermal glare from the surface disappeared.

Based on that success, several other more permanent surface treatments were tested, including colored films, diffusing films and opaque films. Several different versions of sanding were tested. The unit of choice for measuring specularity was taken from the steel industry (which produced the polished steel plates) paper and paint industry, namely “gloss units.” (See Table 1.) A

satisfactory reduction was found that did minimal damage to the aesthetic appearance.

All of the surfaces which qualified as glare sources based on the earlier computer simulations were thus treated at a cost of ~USD 90,000 for the Founder’s Room and ~USD 20,000 for the REDCAT marquee. The complaints of thermal and visual glare ceased.

**POST TREATMENT EVALUATION OF WDCH**

Subsequent to the remediation of the Disney Concert Hall, photographs were again taken of key locations and digitized. New histograms were made and studied. [13]

Although the personal observations indicated that there was much less glare, the histograms still indicated glare. Several possibilities were noted.

1. The range of the original images was not sufficient to record the higher ratios of glare luminance to background luminance. Thus, the Ward “thresholds” (greater than 7:1), although present, were never achieved in the digital photographs.

2. A critical factor in determining relative glare in exterior situations is the sky luminance. A relatively “dark” clear blue sky as background yielded greater ratios than a somewhat overcast sky. Thus the relative glare metrics suffered from variable sky conditions when applied to exterior evaluations.

3. Although *relative glare* was present, it was not the determining factor. The prime candidate became *absolute glare*.

4. Alternatively, it is also possible that the “improvement” was merely a by-product of the placebo effect, i. e. there was no significant change, but since something was done, everyone was happy. Although this was a possibility, it did not coincide with personal observations, which consistently indicated a perceived improvement, even (or especially) to the untrained eye.

There was a significant reduction in measured temperatures of lightweight surfaces held in the focal points, but no significant changes in the concrete ground temperatures, which still remained elevated compared to points measured outside the range of the (now somewhat diffused) reflections. The same dates were measured before and after the remediation and the weather was similar.

It was concluded that there was originally visual glare present and that it was still present, but greatly reduced. The histograms, however, were not capable of discerning the difference with the luminance ranges tested. Either

the primary source of visual glare was absolute glare, and/or the histograms were not effective in measuring the difference, especially given that the images were not high dynamic range (HDR).

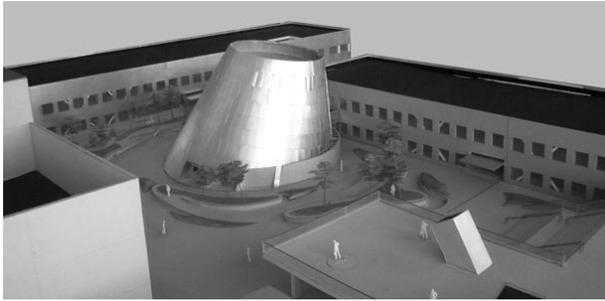


Figure 0: Metal Skinned Library in High School for the Arts

**LOS ANGELES UNIFIED SCHOOL DISTRICT  
HIGH SCHOOL FOR THE ARTS BY COOP  
HIMMELBLAU**

The original design for the LAUSD High School for the Arts included a large clipped cone made of stainless steel, housing the library in the center of the courtyard of the complex. The LAUSD, determined not to repeat the mistakes of the Disney Concert Hall, retained the services of the author to evaluate the possibility of thermal and visual glare, both in the courtyard and in the surrounding buildings, which might result from the cone. (See Fig. 3)

The cone was simulated from different views within the courtyard and there were luminance levels well in excess of the 12,000 cd/m<sup>2</sup> absolute glare threshold. Simple angle calculations of the summer and winter altitude angles indicated the areas that would be subjected to the thermal and visual glare. Windows in the surrounding buildings and the open recreational courtyard were clearly affected.

In this instance, the architect was reluctant to modify the exterior surface of the library, but the owner was in control of the surrounding environment. Modified window treatments including exterior shading devices, low-e glazing and interior reflective blinds were recommended for buildings facing the cone. An extensive landscaping plan for the courtyard area was proposed, which included bushes and vertical trellises for low angle reflections combined with high crowned trees for second storey reflections. Despite the benefits of xeriscaping, ground cover capable of significant evapotranspiration was recommended.[14] This might be debatable, but Spanish style courtyards in Southern California have historically been passively self-cooling, using shade and a source of latent heat exchange. This does require some water.

**LEWIS SCIENCE LIBRARY**

Gehry and Associates was selected by Princeton University to design their new Lewis Science Library. The proposed design was clad in glass, brick and textured rolled steel. It is adjacent to an intersection which could be strongly impacted by visual glare reflected from some of the metal facade and roof segments.

The university was well aware of the possible difficulties related to glare and required Gehry to contact the author to determine if there would be difficulties. Gehry Technologies and the author both did simulations which showed the likelihood of glare in only one important location. (See Fig. 4)

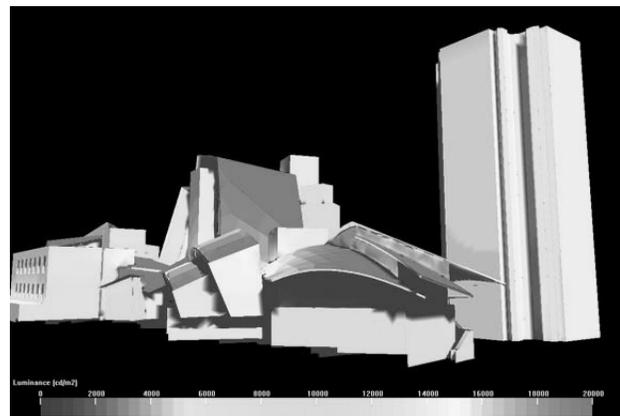


Figure 4 : Princeton Library (>20,000 cd/m<sup>2</sup> = gray in figure)

Based on the measured specularity of the surface and the simulation luminances in excess of 20,000 cd/m<sup>2</sup>, it was recommended that the traffic intersection be shielded from the building or the material surface treatment be adjusted to lower levels of specularity. Specific tree varieties with minimum foliage densities were considered to shield the intersection from the reflections. In that climate and at that distance, it was concluded that the landscaping would be sufficiently robust to endure the added radiant gain.

**URBAN RESIDENTIAL TOWERS**

A set of Residential Towers are to be built occupying the block between Grand and Olive, First and Second Streets in downtown Los Angeles, across from the Walt Disney Concert Hall. A proposal for the tower on the Southwest edge of the site is clad in an undulating glass curtain wall. The CRA (Community Redevelopment Agency) required consideration of the glare issues posed by different glazing materials.

The building was simulated in three different software packages: Lightscape, Radiance and 3D Studio Max to allow comparisons of output. The undulations

produced multiple concave surfaces at varying heights on the buildings.

In this instance, comparisons showed that both Radiance and 3D Studio Max were capable of showing the specular secondary reflections as mapped onto matte surfaces. Thus, a single simulation could check for multiple glare foci. (See fig. 5)

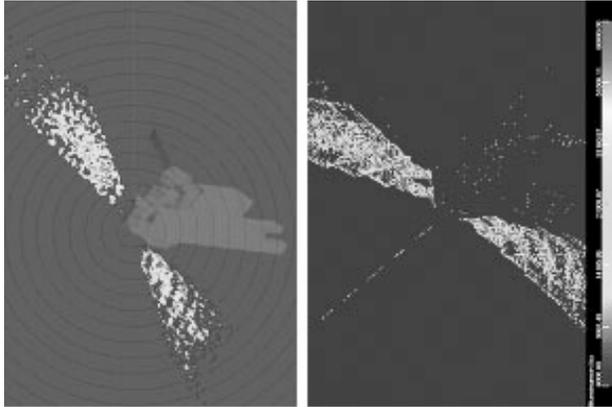


Figure 5 : Radiance and 3DstudioMax Luminance Plots of Glare Reflected onto Surrounding Ground Plane. Sun is at Southwest Position.

It was clear that there were glare spots when the reflectance of the glazing was in the 70% range. Furthermore, it was clear that there were waves occurring in the reflected light, similar to the refraction on the bottom of a swimming pool. A careful examination of the façade showed that in addition to the focal points of the individual undulations, the collective undulations formed an array which had separate focal points with contributions from multiple undulations. (See fig. 6.)

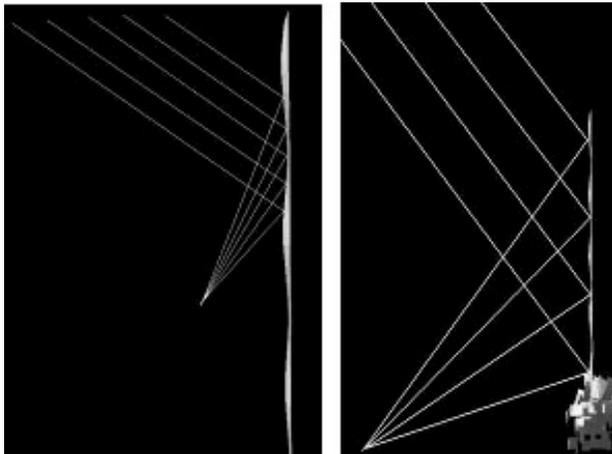


Figure 6 - Single Focus from Single Concavity and Array Focus from Portions of Multiple Concavities

Several solutions were suggested, including surface shading in the form of overhangs and fins, or smaller panes and deep mullions, but these solutions resulted in a huge change in the aesthetics and openness of the buildings. It appeared that the only solution was to adjust the reflectance of the glass until the reflections were reduced to a tolerable level, while still not completely overloading the HVAC system of the building. This necessitated multiple iterations of the building with different glass types. In the end, a Viracon VRE 1-46 glass was chosen, which reduced the reflected glare below absolute threshold levels and below levels typical of the surrounding urban environment.

### SUMMARY

There is great variation in which solutions work best in which situations. In taller buildings, surface articulation, surface treatment and the modification of form are almost always required. In some instances the solution to the glare issue increases the internal gains of the building, which is a difficult trade-off. In shorter buildings, surface articulation, freestanding trellises, fins, overhangs and landscaping become prime possibilities. In cooler climates, landscaping becomes a robust solution. There are limitations of scope for each of the solutions.

### CONCLUSION

Further work needs to be done in multiple areas. Similar cases need to be tested, before and after, using HDR (High Dynamic Range) images to see if there is a consistent pattern in “relative” visual glare, as well as the thermal and “absolute” visual glare.

Similar studies should proceed using the Ward “thresholding” method which simply uses the 7:1 ratio between the average for the entire image and the peak values of the glare source for identifying glare sources. Although this method was developed for calculated images, it holds great promise if it can be empirically verified and employed for all cases.

Other relative glare indices should be tested on the case of the Disney Concert Hall.

Separate tests for relative and absolute glare should be pursued.

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