An Analysis and Simulation of Curtain Wall Reflection Glare

Naai-Jung Shih and Yen-Shih Huang

This paper presents a computer-aided visualization on the influence of reflected sunbeams from curtain wall buildings. A survey was made to local buildings and it was discovered that reflected glare is a significant urban problem. Based on survey findings, a simulation was conducted to compare with actual occurrences in order to increase the comprehension of the consequences of window orientation and angles in the design stage. The simulation enabled design evaluation with an inspection above normal eye level and in a broader area, than that which normally could be achieved in a site survey at a pedestrian’s or a driver’s level. The computer simulation verified the influence of reflection on the urban environment by using a time-based record. In order to provide design solutions, the simulation used a 10x10x10 cube in referencing the horizontal area that would receive reflections. Due to the symmetric shape of the cube, a butterfly shaped boundary of reflection area (BRA) was concluded. BRA is smaller on the summer solstice than on the spring or autumnal equinox. In order to reduce BRA, a passive design approach was applied by tilting or rotating walls to evaluate how the tilted angles or orientation of the façade could affect reflected glare.

**Keywords**: reflection glare, visualization

**Definitions**

It will be helpful to begin by defining some of the important terms being dealt with in this paper:

Firstly, glare generator (giver, reflector) and glare receiver (taker):

- glare generator (giver): surfaces or buildings that reflect sunbeams; a reflecting building
- glare receiver (taker): surfaces or buildings that receive reflected sunbeams, could also be a street or an open space; a building being reflected

Second, glare volume or the volume of glare: the volume defined by glare giver and receiver, for example, the space between glass curtain wall and ground or the façade upon which glare to cast onto

Thirdly, the boundary reflection area (BRA): the boundary of the glare on the glare receiver

**Introduction**

A limited availability of land in urban areas has lead to increased construction of high-rise buildings. The number of high-rise buildings has significantly increased over the past 20 years at local area. Most of the buildings use curtain walls to enrich the color and form of the façade. Although an energy conservation code in effective for several years has
helped to reduce solar impact, the number of glass curtain wall buildings is still increasing. Instead, a great amount of reflection glass (reflectivity of 20-40%) is used to lower the cooling load. The goal of energy conservation was achieved to a certain extent, however, with the tread-off of reflected glare. The reflected sunlight not only casts surplus light but also adds a supplementary thermal load to the neighborhood environments. In some case, buildings receive reflected sunlight from two sources.

Although related departments in local city government have received complaints from people who work in offices affected by glare, little action can be taken against the source. Detailed reflected glare related regulations or rules were not even included in local building codes. It appears conflicts between energy conservation and reflected glare may continue to arise in existing and future regulations.

**Research goal**

The purpose of this paper is to understand visually how the reflected glare from a glass curtain wall building may affect the surrounding buildings or environment. This study applies computer-aided visualization to measure the influence of reflected sunlight in terms of volume and projection area of the reflected glare, by referring to survey results. The quantitative evaluation eventually leads to suggestions for design development of forms such as tilt angles of walls or orientation of plans.

**Reflection glare**

Russia recently tried to reflect sunlight to mid-Asia by using a 20-meter-wide aluminum disk on an orbiting satellite. It was expected that the reflected sunlight will cover a belt 5 km wide and be 10 times as bright as the moon. Although this plan did not succeed, this experiment made people think whether or not reflected glare exhibits the characteristics people demand from the sun. How will reflected glare that comes from glass curtain wall influence the environment?

Reflected glare becomes less desirable if it accidentally or improperly falls within a person’s visual cone and intrudes upon his/her work. Reflected glare is different from the influence of a permanent shadow cast from high-rise buildings, since glare causes immediate discomfort to people and can lead to potential fatigue or danger [1, 4-6]. Shadows at different time intervals are always overlaid to illustrate the region of permanent area that is free of daylight. In contrast, any point located within an area swept by glare will be influenced. Although it only takes a pedestrian or a driver a short period of time to pass through reflected glare, the influence will become obvious while building façade gets wider.

Types of reflected glare can be categorized into fast, moderate and slow speed based on the relative movement of the object generating the glare and the object influenced by the glare:

- **High speed**: While driving a car, the reflection usually comes from the sun that accidentally hit chrome edges, side mirrors, or the rear window of the car in front or a glass curtain wall on the street. Whether reflection exists or at what level of strength depends on the buildings next to street or the relative movement of the car and the cars following it.

- **Moderate speed**: This relationship exists between, for example, the curtain wall and a pedestrian. The glare that comes from the former moves slowly, in contrast to the speed of a pedestrian. People may pass through the glare volume in a relatively moderate speed, compared to a driver.

- **Slow speed**: This relationship exists between a building and others as a pure movement of glare. The speed comes from the slow movement that makes some workers suffer in a fixed location for relatively long period of time, if the place they have to stay is located within the volume of the glare.

**Survey**

A survey was made of 31 local buildings that use glass curtain walls and cast an obvious reflected glare. The period of the survey was between August and
Researchers started from studies of city maps and previous curtain wall building surveys in order to select candidates that would have a potentially high opportunity to reflect glare. Those buildings were organized by road name. Photos were taken of each site in the morning and afternoon, and it turned out that more buildings were recorded than expected because some windows of a small size also reflected glare. It seems that no matter how large the size or boundary a window or a curtain wall is, reflection occurs even in a deeply recessed facade. The survey also showed that glass covered with dirt also cast glare.

This survey led to a conclusion that reflection glare is a significant urban problem. Most of the buildings reflecting sunlight were commercial or office buildings. Buildings receiving the reflected glare were mainly located in residential areas or in a region with a mixture of residential and office buildings. This represents a lack of consideration of the glare impact in the construction of offices next to residential areas.

<table>
<thead>
<tr>
<th>face-to-face reflection</th>
<th>neighborhood reflection</th>
<th>irregular reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Most occurrences are located next to 20 meter road.</td>
<td>1. Most occurrences are located next to the roads running east-west without constraints of road width and solar angle.</td>
<td>1. Occurs when new office buildings are located next to old residential areas.</td>
</tr>
<tr>
<td>2. Glare starts at PM 4:00 if the angle of elevation is lower than 30.</td>
<td>2. A relatively high occurrence (60% of survey cases)</td>
<td>2. Irregular site, difficult to predict glare</td>
</tr>
</tbody>
</table>

An important observation was that pedestrians and drivers ignored the presence of glare, even with an obvious body reaction like hand masking or a turn of the head. Sometimes the researchers didn’t notice the presence of glare at certain locations until site photos were compared to computer simulations side by side. It was quite surprising that some occurrences of reflected glare were not obvious because edges were blurred after being cast to a distant place. Survey photos showed that at some sites only blurred spots were observed.

Table 1 (left). Types of reflection

An effective influence of reflection is recognized when any façade receives continuous and sharp glare on more than 10% of its surface area between AM 10:00 and PM 2:00. The survey was conducted on curtain wall buildings located next to roads wider than 20 meters. Roads selected were mainly in a north-south and east-west direction. Observations and recording were made with emphasis on the relationship between site and glare type. Buildings with obvious glare were among the first group photo recorded. Types of reflection are listed in Table 1.

Types of reflection:

- **face-to-face reflection**
  - Most occurrences are located next to 20 meter road.
  - Glare starts at PM 4:00 if the angle of elevation is lower than 30.

- **neighborhood reflection**
  - Most occurrences are located next to the roads running east-west without constraints of road width and solar angle.
  - A relatively high occurrence (60% of survey cases)

- **irregular reflection**
  - Occurs when new office buildings are located next to old residential areas.
  - Irregular site, difficult to predict glare

- **full reflection**
  - Clear edged glare can be found on building façade. This type of reflection is emphasized in this study.

- **fragmental reflection**
  - Edge of glare is blurred.
  - Window frames divide glare into fragments.

- **masked reflection**
  - Caused by mask on façade, edge of glare is either distorted or discontinuous.
of light were cast on a street or a façade. Without the assistance of the computer simulation, it would have been difficult to picture the influence boundary.

**Visual simulation of a real case**

Based on the findings from the survey, simulation was compared to occurrence on site to facilitate the comprehension of the influence of building details in the design development stage. Visual simulation was conducted by constructing an urban mass model, designating solar variables, characterizing façade features, and ray-tracing sunbeams with a computer application (see Appendix A). In order to simplify the simulation process, several assumptions were made:

First, rays from sun were assumed to be parallel and the corresponding light type was chosen in the application.

Second, the solar angle was assumed the same because a difference of 8 minutes does exist between the east (Altitude 122) and west coast (Altitude 120) of the local area.

Thirdly, solar time has a difference from daytime by less than 15 minutes. Real solar time was used.

A real case was simulated and compared with the photos taken on site (see Appendix B). Result showed that tolerance existed that might come from man-made mistakes, the tolerance of the recording, solar angle, or model construction. The computer simulation verifies the influence of reflection on the urban environment in a time-based record.

**Visual simulation of a test cube**

Many off-shelf three-dimensional applications allow users to define surface attributes like reflectivity (Paul et al, 1995) but fail to bounce light beam in order to describe BRA. Applications, which apply Radiosity to simulate the effects of light and shadow, may need additional efforts in recording, tracing, and calculating BRA over a day (Gregory, 1994).

In order to provide design solutions, the simulation used a cube of 10x10x10 footage as a reference in comparing the area that is being reflected to the ground. All four facades of this cube were made of reflective materials similar to curtain walls. Test results showed that reflection glare usually splits into two parts except the moment when the sun is oriented due east, south, or west. A union (see Figure 2.), instead of intersection, of the boundary of reflection area (BRA) was used to evaluate glare influence from AM8:00 to PM6:00 at a 2 hour interval because, first of all, early morning sun is still striking regardless of how low the temperature is; and the second, the glare swept region is characteristically different from the concern that occurs to shadow. The boundary of the glare union was then exported to a drawing program to trace the boundary and calculate the area on the ground level.

Due to the symmetric shape of the cube, a butterfly shaped BRA was concluded (see Figure 3). The symmetry is important because this shape has usually been ignored in previous surveys because of limited access from the street side. BRA is smaller on the summer solstice than that on the spring or autumnal equinox (see Figure 4.). In order to reduce the BRA, a passive design approach was applied by tilting walls. Tilting walls 10 to 20 degrees reduces BRA up to 48% on the south and north walls than that on the east and west walls. Nevertheless, a rotating plan enlarges BRA up to 73%.
An indoor simulation was also conducted to visualize the influence on office staffs, for example if a low beam falls directly within a person’s vision cone or a high beam bounced upward from a desktop while a person was looking down (see Figure 5.). The intersection of a building and the glare volume subjected to a reflection influence was also calculated in order to visualize the real boundary of impact in the indoor area.

**Conclusion**

This survey showed that reflected glare is a significant urban problem. The visualization proved that the problem could be even worse in cases where hidden glare might exist. Being aware of the influence is the first step toward solving the problem. The solution eventually should be enforced through building codes in terms of improvements in design or building materials. As to the educational purpose, the findings of this research will raise students and designers’ attention as well as awareness of the potential influence of design in environmental evaluation.

Future research would include data collection of regions or cities at different altitudes in order to discover and categorize types of occurrences. With the assistance of better and more efficient tools in computer-aided visualization, more study-oriented statistics can be collected to substantiate the contents of building codes. The scope of a related study covers the roles of individuals who may in some way be connected to the issues of reflected glare, such as designers, building managers, window suppliers, researchers, offices from the city government, traffic bureau (including airport), and architecture professional institutes.

**References**

## Simulation process of reflected glare

<table>
<thead>
<tr>
<th>procedure</th>
<th>site</th>
<th>simulation</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>model 3D mass</td>
<td></td>
<td></td>
<td>Date: AM 8:20, Aug. 2, 1998</td>
</tr>
<tr>
<td>ray-trace cast shadow</td>
<td></td>
<td>retrieve the boundary of shadow that sunbeam cannot reach</td>
<td></td>
</tr>
<tr>
<td>grab the surface of glare generator</td>
<td></td>
<td>1. export file to image editing application, 2. define boundary</td>
<td></td>
</tr>
<tr>
<td>modify surface attributes</td>
<td></td>
<td>1. define effective reflection boundary by blacking out and inverting shadow area, 2. adjust contrast level</td>
<td></td>
</tr>
<tr>
<td>build mask</td>
<td></td>
<td>1. generate mask and select it as main reflection surface, 2. paste mask on the surface of glare generator</td>
<td></td>
</tr>
<tr>
<td>simulation result</td>
<td></td>
<td>compare to site photo and estimate the tolerance of reflection</td>
<td></td>
</tr>
<tr>
<td>results</td>
<td></td>
<td>compare to site photo and illustrate the damned for detailed modeling of curtain wall frames and glass transparency</td>
<td></td>
</tr>
</tbody>
</table>


T. Lwata, K.I. Kimura, M. Shukuya and K. Takano, Discomfort Caused by Wide-source Glare,
<table>
<thead>
<tr>
<th>Time</th>
<th>Solar Angle</th>
<th>Plan</th>
<th>South-East View</th>
<th>North-East View</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM 6:00</td>
<td>elevation: 11.3, orientation: 69.1</td>
<td><img src="image1" alt="Plan Diagram" /></td>
<td><img src="image2" alt="South-East View" /></td>
<td><img src="image3" alt="North-East View" /></td>
</tr>
<tr>
<td>AM 8:00</td>
<td>elevation: 37.3, orientation: 78.6</td>
<td></td>
<td>The two angles show that reflected glare does exist at places which were not recorded in photos.</td>
<td></td>
</tr>
<tr>
<td>AM 10:00</td>
<td>elevation: 64.2, orientation: 87.4</td>
<td></td>
<td>Comparing to site observation, tolerance in glare comes from the lower level of details.</td>
<td></td>
</tr>
<tr>
<td>AM 12:00</td>
<td>elevation: 88.5, orientation: 180.0</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>


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