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Assessing reflected sunlight from building facades: A literature review and proposed criteria

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A B S T R A C T

In recent years there has been a growing awareness of the risks posed to people and property from uncontrolled solar reflections from the built environment. Despite the severity of the risks, there is surprisingly little regulation regarding such reflections. Presumably, part of the reason for this lack of regulation is that there are no universally accepted criteria from the scientific community defining acceptable limits of reflected visible light and thermal irradiance in the urban realm. Without appropriate guidance, the regulations which are employed by cities may not be appropriate and designers have no means to judge the impact of a potential building's reflections until after its built. This paper presents a review of existing regulations and metrics related to the impact of visible light and thermal energy on people and property. It also proposes quantitative criteria which the authors have developed for use in design and construction in order to help architects and designers understand the level of impact their building's reflections will have on its neighbors. The literature that the proposed criteria are based on is still limited in breadth. It is our hope that the research and design communities will further develop the criteria and tools that will benefit designers and city regulators.

1. Introduction

For people living in cities, seeing reflected sunlight from a building is a common experience, and while this can sometimes be an annoyance, we mostly accept it as part of urban life. However, buildings can cause more severe impacts owing to the type and coverage of glass on the façade and also curvilinear designs. A well-publicized example of significant reflections was the Disney Concert Hall in Los Angeles [1]. It had a significant area of polished stainless steel, which combined with the concave facade geometry, would reflect and sometimes focus light within the neighborhood. This led to heat gain issues at sidewalks and inside surrounding buildings. The bright reflections also posed a visual distraction to drivers. Ultimately, parts of the façade were roughened to help scatter the reflections, reducing their intensity. More recent examples of reflected light causing distraction or damage include the Shard in London [2], Museum Tower in Dallas [3], the Vdara Hotel in Las Vegas [4] and 20 Fenchurch in London [5]. The latter two buildings reportedly focused enough sunlight in pedestrian areas to cause burns on a guest and damage a car with radiant heat, respectively. Buildings are not the only potential sources of dangerous glare from the built environment; photovoltaic (PV) panels [6] and even art installations [7] have been blamed for visual and thermal issues related to reflected sunlight as well.

The well-publicized nature of these events has led to increased awareness in the design community, and a desire to understand how a proposed building will interact with the sun. As consulting engineers in the field of building science, the authors have been asked with increasing frequency: "*How will reflections from my building affect its neighbors?*" With little guidance available from governing bodies we endeavored to create suitable criteria to assess the visual and thermal impacts of reflected light from the built environment. These criteria were developed and refined through a review of available literature across multiple scientific and engineering disciplines as well as through experience gained from the analytical and physical study of reflections from several buildings around the world.

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2. Review of existing regulations regarding reflected light

Despite the risks that glare can pose to people and property, there is little regulation around it. The Federal Aviation Administration (FAA) in the United States has recently introduced provisions to reduce the risk of visual glare distracting pilots and air traffic control (ATC) personnel [8]. However this is limited to potential glare from solar energy systems on airport property only. German federal law classifies light as an "emission" to the environment much like noise or exhaust [9] and a recent decision by the German Federal/State Working Group for Pollution Control (LAI) indicates that this includes reflections [10]. It also defines any PV system which causes glare for more than 30 minutes per day or 30 hours per year as a "nuisance", but again this regulation does not extend to facades in general. Many cities have guidelines related to glare from building facades, but the majority of them only indicate that an analysis of the glare impact should be undertaken, usually at the discretion of the city. Often no clear guidelines on the surfaces to be studied, the criteria to be used or what constitutes acceptability are defined. Only a few cities have implemented prescriptive measures which aim to limit glare; typically by restricting the use of façade materials which reflect more than a prescribed percentage of incident light. Several Australian cities limit the normal reflectance of any glass façade element to no more than 20%. Sydney takes this one step further and applies the limit to all façade materials [11]. Building authorities in Singapore, Hong Kong and Shanghai set similar limits on façade reflectivity [12–14] but this type of regulation remains rare outside of southeast Asia and Oceania. The city of Dallas, Texas is the only North American city known to the authors that attempted to pass similar legislation, but it was ultimately abandoned during the public consultation phase. Prescriptive limits on façade material reflectivity are attractive regulations because they are easy to understand and straightforward to enforce, however they overlook several important aspects of the physics of reflected sunlight.

Firstly, using a single prescribed reflectance limit fails to acknowledge that the reflectance of a surface is *not* a fixed value. When light moves from one medium to another, two things happen at the interface; some light transmits through the interface into the second medium and the rest is reflected back in a new direction. The fraction of light which is reflected or transmitted can be determined using the Fresnel Equations, which state that regardless of the indices of refraction of the two materials, the fraction of reflected light approaches 100% as the rays of light impact the interface at more glancing angles. As an example, a single pane of 6 mm clear glass will reflect approximately 8% of visible light for light rays that strike perpendicular to the exterior surface of the glass. For rays that strike within 50° of perpendicular, the reflectance remains roughly constant; however, as the rays strike at angles approaching parallel to the reflecting surface, the reflectance rises rapidly to 100%. This is illustrated graphically in Fig. 1 using data generated by Lawrence Berkeley National Laboratory's WINDOW v7.2 software [15]. (In the chart, 0° indicates an incidence angle perpendicular to the reflecting surface.)

Glazing manufacturers typically only specify the reflectance of glazing for light striking it perpendicularly. This is frequently misunderstood by designers who think that the "low reflectance" glazing will prevent any issues of glare. However, depending on the orientation of the façade and the location of the sun in the sky, the façade could be reflecting significantly more light than would be expected based on the manufacturer's specification data.

Furthermore, these types of regulations often only consider how reflective the surface is to *visible* light and ignore how much of the sun's *thermal* energy is reflected. Many years ago this distinction would not be significant, as traditional windows reflect visible and thermal energy to approximately the same degree. Today, high-performance glazing systems are available which often employ low-emissivity coatings. These products can be significantly more reflective to thermal energy than they are for visible light. As an example, consider the common "Solarban 70XL" glazing system, manufactured by PPG Industries. According to the manufacturer [16], typical double-pane glazing systems using Solarban 70XL, reflect between 5% and 21% of exterior visible light, which mostly fall within the prescribed reflectance limits discussed earlier. But, when the glazing's reflectance is averaged over the full solar spectrum (i.e. ultraviolet, visible and infrared radiation), the reflectance of some systems can increase dramatically. In the case of Solarban 70XL employed with two panes of clear glass, the full spectrum reflectance is more than four times the visible reflectance. This is an important nuance as the heating of an object will be driven by both visible and thermal energy. The effect that Solarban 70XL has on the visible and full spectrum reflectance of a single pane of 6 mm glass is also illustrated in Fig. 1.

Another shortfall of prescriptive regulations is that they typically do not consider the nature of the impacts (i.e., the "who" or "what" being impacted), nor the frequency and duration of the reflections. A visible reflection that falls on a pedestrian could be benign in many situations but when it aligns with a vehicle driver's required line of sight and impairs their vision, it becomes a danger. Similarly, a short duration reflection is unlikely to cause significant heating or damage to surrounding vegetation or man-made objects, but the longer the exposure, the higher risk of the potential adverse thermal impacts.

Finally, to stipulate a general upper limit of reflectance to any one unit of a glazing assembly does not account for the building's shape. In particular, a concave shaped facade can potentially concentrate reflections in one area and a convex shape can cause repeated reflections over a longer period of the day over a broader area of the surrounding neighborhood. As façade designs become more complex, these impacts become harder to intuitively predict. For example, a single surface adhering to a 20% maximum reflectance limit may not cause problems, but if a number of these individual surfaces create a focal point (e.g. a façade with a concave curvature, illustrated in Fig. 2 above) the thermal effects would be additive and could ultimately cause thermal discomfort or burns on people or damage to plants and materials. Situations such as these are often the culprit in cases of extreme reflection related damage, which have been dubbed "death rays" by the media.

Due to these limitations with existing prescriptive limits, it is the authors' opinion that a more qualitative, analytical approach be taken to assessing the impact of urban building reflections.

3. Review of existing reflection impact metrics

A current limitation with regulating urban reflections is that there is a lack of widely accepted metrics for defining the full impact of a building's reflections on its surroundings. This is at least partially a result of the subjectivity of how an individual experiences a bright light. This experience is dependent on a variety of factors including what the person is doing, their expectations, their age, etc. Therefore, there is currently no universally accepted metric for the impact of day light even within the transportation and lighting communities.

A separate issue from visual impacts is the impact of reflected *thermal* energy. There is limited research available on how much reflected energy is "too much" from a building. Beyond the issue of intense focused reflected thermal energy and its impact on human safety and material damage, are more subtle questions about human comfort and even additional cooling loads for adjacent buildings.