Title: **When Buildings Attack Their Neighbors: Strategies for Protecting Against "Death Rays"**

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Subject: Façade Design

Keywords: CFD
Façade

Publication Date: 2015

Original Publication: CTBUH Journal, 2015 Issue I

Paper Type:
1. Book chapter/Part chapter
2. **Journal paper**
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

When Buildings Attack Their Neighbors: Strategies for Protecting Against "Death Rays"

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"In Singapore, solar reflectance of construction materials is limited to not more than 20%, and authorities have considered lowering that threshold to 15%."

Some recent high-profile skyscraper designs that employ extensive exterior glass paneling have generated solar reflectivity, causing negative outcomes, such as melting plastic car parts and creating hazardous glare to neighboring buildings and nearby traffic. Solar reflectivity can also raise surface temperatures on adjacent properties and kill vegetation.

Building energy modeling can be invalidated if light reflected from neighboring buildings is not taken into account. Today, Computational Fluid Dynamics (CFD) can be used to offer an accurate and advanced study that predicts not only the location of reflected light, but also the intensity of these reflections and the related temperature increase originated by the reflected light. In this way, CFD can help designers limit solar reflectivity effects from their buildings.

Introduction

The undesirable designation of "death-ray building" has a basis in history. Archimedes used an array of mirrors to set adversaries' warships on fire during the Siege of Syracuse (214–212 BC). This piece of weaponry has been known as "the Death Ray" ever since. Today's death rays emit from tall glazed buildings earning them the nickname "fryscrapers."

Basic optics laws tell us that when a light ray travels in a medium and encounters a glass surface, for example, part of the incident ray is reflected and the rest is transmitted to the other side of the glass. Depending on glass characteristics, the light transmitted exhibits different ranges of phenomena such as heat-gain. Reflections produced by glass and other smooth and polished surfaces is called *specular reflection*. The reflection from rough surfaces is called *diffuse reflection*.

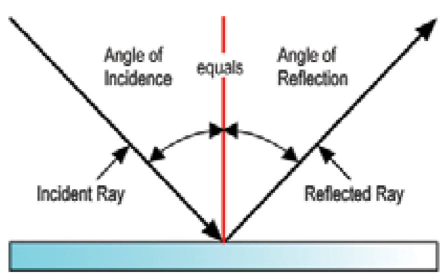

Figure 1. Reflection law. Source: Tippens, P. 2005. Physics. New York: McGraw-Hill Science/Engineering/Math.

The scope of this paper includes the portion of the incident ray that is "bounced" back to the medium and will be referred to as "reflection" from this point. Although reflectivity issues are not exclusive to glass, this paper focuses on glass due to its predominant use in contemporary architecture.

The reflected light's directional behavior is described by the reflection laws (see Figure 1):

- The incident angle is equal to the reflected angle.
- The incident ray, the reflected ray and the line perpendicular to the surface (the normal) are located on the same plane.

With advances in technology and enough computational power, these theories and principles that were developed over three centuries ago, and which constitute the basis of optics, can now be taken to a new level in the world of 3D applications.

The Demand for Skyscrapers That Sparkle

The built environment has seen an increased demand for skyscrapers that maximize views through extensive exterior glass paneling. The solar reflectivity phenomenon has generated attention lately due to the increase in heat that buildings can produce, which has resulted in significant property damage and distracting glare.

We must remember that "light" is not only that which is visible, but that it comes in the form of thermal load. Light is comprised of different components: ultraviolet (UV) radiation, visible light, and infrared. Light reflected off buildings carries all three components at different scales, based on material properties.

With the use of reflective glass, spectrally selective coatings, and advanced glazing in general, it is imperative to study solar reflectivity at a level that covers both visual and temperature increase effects in order to evaluate results on a project's surrounding environment.

Increasingly complex geometries in buildings, in concert with a more elaborate palette of exterior materials, have exacerbated the effect of reflected light from some glazed buildings. Unfortunately, many designers have limited their study of solar reflectivity by using rudimentary analytical tools that, while providing an accurate prediction of the path of reflected light, do not predict the intensity of this reflection. Such tools are limited to single ray-tracing computations and can typically be found in commercially available design software as one of many built-in functions. On the other hand, using CFD, one can accurately predict the location of reflected light, the intensity of these reflections and the theoretical temperature increase caused by light reflected off buildings.

Figure 2. London's 20 Fernchurch Street's façade reflects sun rays onto a nearby street. © Simon Price

Glare in the airspace can be also be predicted using this technique in order to comply with the civil aviation regulations for buildings and structures at or near airports. For example, the US Federal Aviation Administration (FAA) regulations require that no visual obstructions be allowed at the air traffic control tower or along aircraft's gliding slopes. Solar reflectivity is considered an obstruction of safe operations at airports. CFD can measure glare in the airspace, which is something that other tools lack today.

Legislation

The last decade has seen an increased number of adverse solar reflectivity cases, in which buildings have "attacked" their neighbors, and their owners have been taken to court. However, many of the plaintiffs have found that the solar reflectivity nuisance has little or no enforcement precedents. Not only are building codes silent on requirements for, or limits on, reflectivity; there is also no industry metric available for defining acceptable performance.

Most city building codes briefly and lightly address solar reflectivity in the same sentence as other types of nuisance such as noise, shadows, and bright paint colors. However, there are two building codes internationally that deal with this matter more categorically. In Singapore, solar reflectance of construction materials is limited to not more than 20%, and authorities have considered lowering that threshold to 15%. In Sydney, Australia, two requirements must be fulfilled; reflectivity of construction materials is limited to not more than 20% and a solar reflectivity study/analysis must be performed.

Driven by recent local events, the City of Dallas made an attempt to regulate this phenomenon. In the proposed legislation, new construction and major retrofits had the option of addressing solar reflectivity on a prescriptive or an analytical path. To qualify under the prescriptive path, building height and reflectance of construction materials were limited. The analytical path would have applied if the previous factors were not fulfilled and/or if the proposed design had convex surfaces, which concentrate light. Unfortunately, this proposal did not survive beyond the public comment phase.

Due to the lack of legislation or industry standards, this problem has not been successfully tackled in court. The cases of buildings that have produced severe damage or disputes regarding solar reflectivity have been addressed by the project's design team or developers. This was the result of a recent case in London, in which the 20 Fenchurch building's concave shape cast concentrated beams of light into neighboring streets (see Figure 2), which were strong enough to melt plastic mirrors and gaskets on cars.

Solar Reflectivity Considerations

Solar reflectivity is a common phenomenon, caused by the interaction between the reflective materials on the façades and the structures around it (Shih & Huang 2000). It can produce discomfort, and can even be a threat to motor traffic when the light is returned in the form of glare.

There are two glare types and two subtypes:

- **Discomfort glare** is caused by two subtypes:
  - **Direct glare** is a phenomenon originated from light sources that cast luminance directly into the eye's visual cone.
  - **Reflective glare** occurs when light rays bounce off a surface and luminance is perceived from the angle of incidence of the reflection.
- **Disability glare** is a luminosity level change significant enough to reduce visibility of the observer.

Most of the cases dealing with the solar reflectivity of buildings are related to discomfort glare rather than disability glare (Shih & Huang 2001).

Below are some of the factors that contribute to solar reflectivity's negative effects on the urban environment:

Figure 3. Discomforting perpendicular solar reflectivity of Campbell Center on road, Dallas. Source: Google Earth

Discomfort to Drivers

Depending on the angle of reflection, drivers could be blasted by reflected light, which could result in accidents. In the late 1990s, a glazed building located near a cloverleaf interchange in Sydney made this issue evident, prompting authorities to account for the phenomenon in building code. According to the UK Automobile Association, nearly 3,000 accidents are caused yearly by direct sun glare. Further, one in every three people commuting through tall building areas in the United States are blasted with reflections from glazed buildings every day .

Depending on topography, geographical location, and season of the year, this issue can be more or less prevalent. The first reaction to direct sunlight or solar reflectivity while driving is to lower the car's visor or look away. But if the reflections are too low to the horizon, the visor will not be sufficient. This can be expected near sunrise and sunset, in the winter months, and in locations at higher than 40 degrees latitude. Reflections or direct sunlight that are at 20 degrees or less from the horizon are likely to be observed by motorists because it will be directly in their cone of vision. The sun's natural position in cities at Seattle or London's latitude will produce daytime solar altitude angles of 20 degrees or less in the winter months and is more likely to produce a reflectivity issue for motorists.

Figure 6. Light reflects off Dallas' Museum Tower through the skylight of the Nasher Sculpture Center onto a Pablo Picasso painting. © Nasher Sculpture Center

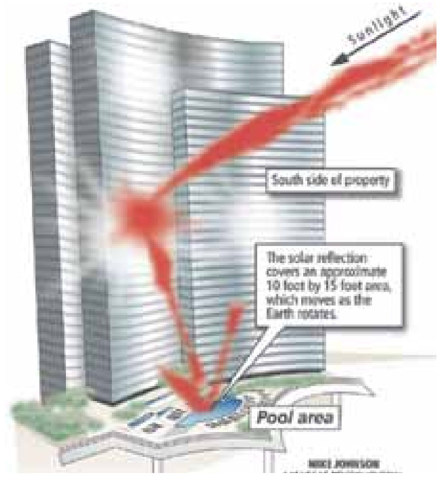

Figure 4. The solar reflection cast during the day from the Vdara Hotel, Las Vegas. Source: Las Vegas Review Journal

In addition to persistent glare parallel to the line of vision, drivers can also encounter quick flashes when the cone of vision is perpendicular to the ray (see Figure 3).

Thermal Loads

Solar reflectivity from buildings can increase temperatures around a given solid, which could result in discomfort and property damage.

Recently, the Vdara Hotel in Las Vegas, the Museum Tower in the Dallas Arts District, and 20 Fenchurch Street in London have been reported to increase adjacent temperatures and cause other issues related to solar reflectivity.

The Vdara Hotel has a south-facing concave geometry that focuses reflected light onto its pool area for most of the day (see Figure 4). It has been reported that these rays have melted plastic bags and cups. Although the ambient temperature increase due to this phenomenon was measured at 11.1°C shortly after this case made the news, it is important to know that plastic bags (polyethylene) melt at around 49–54°C and plastic cups at around 71°C.

Figure 5. The Museum Tower, Dallas © Steven Henry

The Museum Tower (see Figure 5) case was originated by a very complex and changing geometry. The tower's elliptical footprint varies in size on every floor, making it elliptical in the vertical plane as well. In order to conquer this elliptical challenge, the curtain wall system is shingled and exhibits more than a 40% reflectance coefficient. Temperatures at reflective hotspots caused by glass on this building was measured at 54°C.

However, this is not the only issue. A neighboring museum, the Nasher Sculpture Center, features a unique skylight with arched glass and perforated aluminum screens in an egg-crate pattern, which allows indirect light into the galleries. But now that this elliptical high-rise is situated right across from the skylight screens, reflections from the tower enter the galleries, exceeding acceptable light levels for some works of art (see Figure 6).

The 20 Fenchurch Street case occurred in September 2013. The building exhibits concavity in the horizontal and vertical planes, earning it the nickname "Walkie Talkie" for its resemblance to the device. According to the London Evening Standard, light reflected from this building was six times stronger than direct sunlight, and caused temperatures at the hotspots to be recorded at 110°C, earning a new nickname, "Walkie Scorchie." Amongst its effects were reports of plastic components of a parked car melting, tile popping, paint blistering, doormats burning, and bicycle seats melting. To temporarily address the issue, a giant net was installed to cover the south-facing concave façade. A permanent solution comprising aluminum fins over the entire façade to prevent solar reflectivity from reaching street level was approved by the City of London in April of 2014.

Nuisance to Neighbors

It is the responsibility of everyone on the design team to consider the effect of light reflecting off their building's surfaces. Depending on the direction of the reflection, it can land on the streets or on neighboring properties. If reflections get into an occupied space, users are most likely to close blinds to avoid interior glare or higher temperatures. Depending on the severity and duration of the glare, neighbors might be forced to keep their blinds permanently closed and are thus unable to benefit from natural light and views.

One of the first cases to produce a significant solar reflectivity problem comes from the Disney Concert Hall in Los Angeles, where curved façades clad in stainless steel projected glare onto passing cars and neighboring condominium towers. The condo owners stated that interior temperatures were increased by at least 9.4°C and that they were forced to keep their air conditioning running to maintain a comfortable temperature. The concert hall was also blamed for trash bins catching fire and traffic cones melting. To resolve the issue, the surface of certain panels was modified to reduce specularity and produce more diffuse reflection patterns.

Energy Modeling Invalidation

Depending on the project's context, intensity, and duration of reflected light, adjacent properties could gain thermal load that was not considered in the energy modeling of the building. This topic goes side-by-side with the nuisance-to-neighbors topic. Condominium owners adjacent to the Disney Hall found their air conditioning systems to be inadequate. Their mechanical equipment was rendered obsolete because it now needed to deal with a sustained addition of thermal load that was not considered when it was originally designed and sized.

Vegetation Decay

Some plants cannot break down nutrients at certain temperatures and will eventually start to decay. With new construction, conditions can be altered and new paths of light and heat can be created by light reflected off buildings. If plants in this context cannot adapt rapidly to new surrounding conditions, they may start to decay (see Figure 7).

Reflectance Properties

Solar reflectivity heavily depends on a material's reflectance properties, which in combination with complex building shapes, can exacerbate the result. Therefore, it is very important to study the project's shape, location, and orientation in order to reduce the severity or incidence of potential issues that could easily be addressed in early design stages.

Energy performance criteria influence architects to use reflective glass to reduce heat gain. However, while highly reflective glass efficiently blocks solar heat gain, it causes a significant impact on the neighboring environment due to exterior reflections. Typical clear glass has an exterior reflectance value of 9%, whereas coated reflective glass exhibits an exterior reflectance value of approximately 20% to 45%.

Glass reflectance coefficients published in manufacturers' data sheets correspond to perpendicular incident light. As the incident light angle changes, glass becomes more reflective – this is known as the "mirror effect" (see Figure 8). This graph tells us that regardless of the manufacturer's reflectance rating, glass can become more reflective at particular angles of incidence.

Selecting Materials to Reduce Reflectivity Effects

Materials such as metal panels and glazing come in several different combinations and reflectance properties that could either help mitigate or exacerbate negative solar reflectivity effects. Metals produce a range of specularity levels, but their surface treatment plays a major role in determining reflectance.

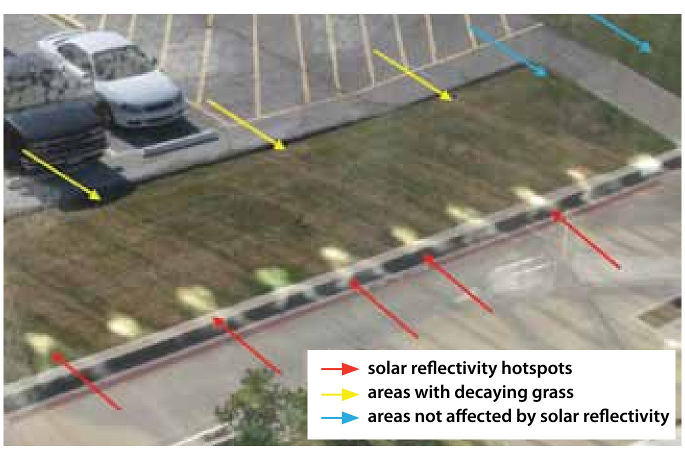

Figure 7. Vegetation decay.

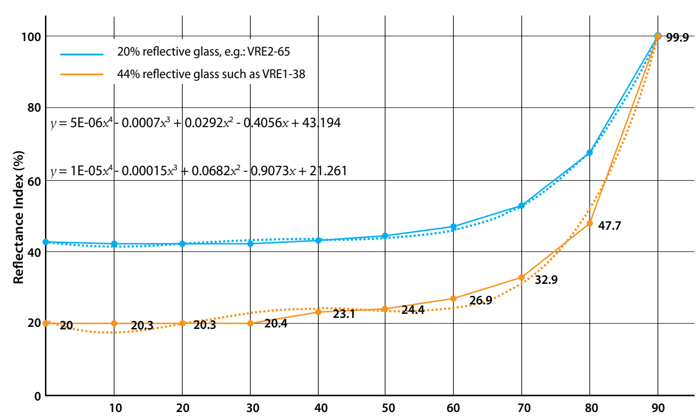

Figure 8. Reflectance vs. angle of incidence.

The range of choice for glass products is immense. Storefront glass, for example, has a low reflectance coefficient (generally from 8 to 12%) in order to afford undistorted views of objects behind the glass. The glass in both the Vdara and Museum Tower buildings has a reflectance coefficient of 44%.

Depending on project conditions, even flat-façade buildings could produce concentrations of reflected light due to the building's positive internal air pressure bowing the glazing materials ("oil-canning") and creating concave shapes in individual glazing units.

Roller wave distortions in float glass can also present reflectivity issues. As heat-treated glass softens during manufacturing, it moves over a series of horizontal rollers, often imparting wave-like distortions in the surface of the glass. These variations across the glass surface can also concentrate light. Concentration of light reflected from buildings caused by oil-canning and roller wave distortions have been reported, observed, and measured in existing buildings.

Acceptance Criteria

There is no general consensus about how much solar reflectivity is "too much." Considering that solar reflectivity can impact the visual and thermal aspect of a surrounding environment, different criteria/indices have been proposed, but none is widely accepted or used. A handful of competing criteria/indices offer some guidance for acceptable performance:

- **Limiting Light Brightness**
  Limiting light brightness certainly addresses the visual aspect of this topic, but it is important to consider that tolerance to light brightness is subjective, since it depends on diverse factors and dynamic circumstances, and is different for every person. Factors such as age, eye pigmentation, eyewear, skin color, contrast, and even eyebrow density play a major role. A specific brightness level might be tolerable for one person but not for the next.

- **Limiting Reflectance of Materials**
  Current regulations in Sydney and Singapore address the solar reflectivity topic by limiting reflectance of construction materials to 20%. Compliance with this limit is is a binary condition, however, that does not allow for increased complexity in building geometries, so reflected light results could be adverse. Visual or thermal comfort could be in jeopardy if buildings otherwise in compliance with this limit concentrate solar reflectivity.

- **Limiting Thermal Radiation**
  Thermal radiation limits are easier to quantify. Some have proposed using National Fire Protection Association (NFPA) guidelines for thermal radiation during a fire event in combination with those of the US Federal Emergency Management Agency (FEMA). Although the proposed threshold of 1,500 W/m^2 is less than NFPA's value, this still can be twice as high as direct solar irradiation at noon. Consider also that solar irradiation varies every month and every minute, and is dependent on geographical location. Using the proposed threshold all year long might yield hot spots during winter months, in which solar irradiation is not as high as it is in summer. In addition, different building materials have melting points of less than 93°C; allowing a high threshold point might place some plastic materials in jeopardy.

- **Limiting Direct Sunlight Effect**
  The question remains: what is acceptable and what it is not? The proposed answer is: "no building's reflectivity should exceed the effect of direct sunlight in its location at any given time of day."

Limiting the effect of reflectivity to no more than what direct sunlight produces could bring conservative results, but it could be implemented with the knowledge that local plant species, materials, and humans are accustomed to such nominal sunlight conditions. Actual temperature readings at solar reflectivity hotspots incorporate both reflected light and direct sunlight. If we limit designs using the Direct Sunlight Effect criteria, temperature increases caused by solar reflectivity will be maintained within acceptable limits.

CFD and Solar Reflectivity

"Death-ray" building cases modeled so far with CFD have been found to exceed nominal sunlight conditions by a factor of up to 12. There are several different companies that offer CFD software, usually at a higher price level than regular lighting or design software. In general, the computational power required to execute some of the models cannot be efficiently handled by regular hardware, due to the number of equations and processes necessary for analysis.

The study of solar reflectivity should not be limited to potential "death-ray" buildings that concentrate light. Conventionally-shaped buildings can also benefit from this type of study as a way of ensuring that the proposed material/glazing is adequate for its environment. Pedestrian comfort and vegetation could benefit from this type of study if properly addressed.

Refer to Figure 9 for a CFD output example. Surface temperature due to direct sunlight predicted for this project is at around 38°C. The temperature accounting for solar reflectivity is at around 42°C. This means that the contribution from solar reflectivity increased surface temperature by around 40°C. Reflectance of glass specified for this project was 12%. With the building shapes such as this, solar reflectivity concentrations are not expected, and more reflective glass

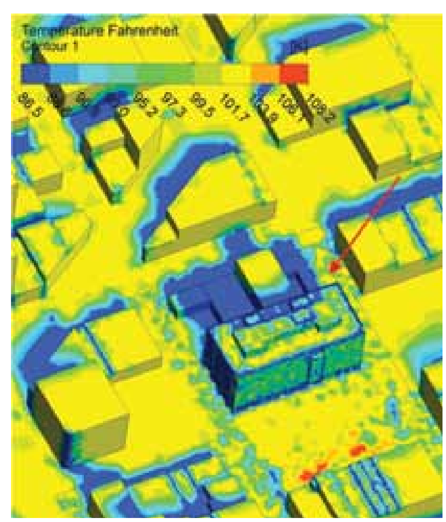

Figure 9. Surface temperature predictions (red arrow indicates the building being studied).

can be used without causing issues. However, it must be verified that neighboring plant species can tolerate higher temperatures resulting from a more reflective glass.

CFD's ray tracing options, solar calculators, fluid dynamics tools, modeling tools, and post-processing analytical tools provide an advanced platform in the analysis of solar reflectivity, making this option a robust and computationally powerful alternative. Figures in this paper were created using a proprietary CFD tool that has been specifically written to address solar reflectivity issues and has been benchmarked several times, proving to be within 4% of as-built conditions (see Figure 10). This 4% margin is caused by discounting the effect of cloud cover, humidity, and wind speed.

In order to evaluate solar reflectivity when designing a building, it is very important to consider the movement of the sun and the interaction with the design in question. Factors that need to be carefully designed and taken into consideration include:

- Highly reflective glass.
- South-/north-facing concave building shapes (in the northern/southern hemispheres).
- Elliptical building shapes in the vertical plane.
- Planar changes throughout building elevations
- Projects near green spaces and pedestrian areas

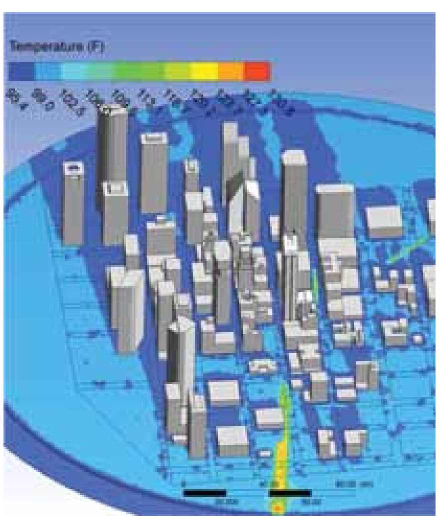

Figure 10. Surface temperature caused by solar reflectivity using CFD.

These are just a few factors to consider, but location and neighboring buildings also affect the path of reflected light and its interaction with the entire project.

If designing for a downtown area or a densely developed site, it is important to consider street width, building orientation, building height, and cladding materials. In these cases, avoiding the potential for solar reflectivity issues could represent a bigger challenge, but it is something that could definitely be avoided or mitigated.

Conclusion

Solar reflectivity has become such a deeply integrated part of urban life that people are no longer surprised by its effects. As long as there is no substantial temperature increase in neighboring properties/environment, and accidents cannot be blamed on solar reflectivity, complaints are few. However, less-obvious effects, such as rising energy bills due to the added heat received from neighboring buildings, are cause for concern.

Highly reflective glazing and spectrally selective coatings are not the only options for optimum indoor performance. Different glazing manufacturers offer similar or enhanced energy performance with less reflective glass. There is no compromise between energy consumption and more benign solar reflectivity products; the only challenge is in designing the building holistically.

Solar reflectivity studies have been in increased demand in the last few years, as designers have become aware of the importance of this type of evaluation. An industry-wide accepted criterion for exterior glare is needed. But it is too early to say when this might be incorporated into design codes, and standards.

As architectural designs become increasingly complex in shape and geometry, the need for reflectivity studies is heightened. CFD has proven to be an accurate and reliable tool in the study of solar reflectivity, as it addresses multiple possible effects from light reflected off buildings. And while it provides accurate predictions of the path of reflected light, intensity, and theoretical temperature increases, it can still be pushed to further limits which are currently under research and development. The options are innumerable. ■

> "There is no compromise between energy consumption and more benign solar reflectivity products; the only challenge is in designing the building holistically."

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