NATIONAL GLASS ASSOCIATION with GANA

Glass Technical Paper FB60-18

Understanding Reflected Solar Energy of Glazing Systems in Buildings

The scope of this Glass Technical Paper is to provide education on design considerations to reduce the possible effects of the reflective characteristics of exterior cladding materials and glazing systems used in building construction. This will include the visible and thermal effects of direct and reflected solar energy which can range from reflective glare effects to reports of material damage.

Introduction

The study of light is subjective in some specific aspects, like color and glare, but very objective in aspects like direction and reflection. Basic optics laws tell us that when a light ray travels in a medium and finds 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 and some other factors, the light transmitted exhibits a different range of phenomena such as heat-gain. Reflection produced by glass and other smooth and polished surfaces is called specular reflection. The reflection from rough surfaces is called diffuse reflection.

The reflected light directional behavior is described by the reflection laws, listed below:

- The incident angle is equal to the reflected angle; refer to Figure 1.
- The incident ray, the reflected ray and the line perpendicular to the surface (the normal) are located on the same plane.

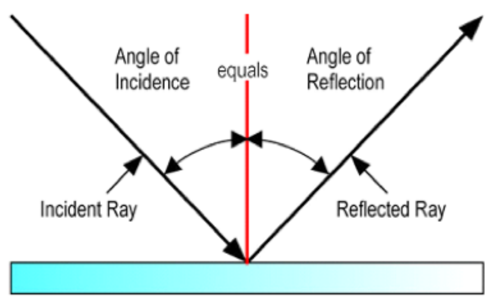


Figure 1: Reflection law.

Contemporary world architecture incorporates a variety of different cladding materials in its designs such as metal panels, stone and masonry, siding, wood, and glass. These materials provide a balanced alternative between esthetics, cost, appearance, energy consumption, color, textures, etc. These materials also offer a wide variety of performance levels for solar control, transparency, light transmittance and light reflectance, amongst others. The phenomenon in which light is reflected off exterior cladding materials back into the environment is called Solar Reflectivity.

We must remember that "sunlight" is comprised of different components, ultra violet (UV), visible light and infrared, refer to Figure 2. These components are associated with different thermal loads and different wave lengths which are not part of this discussion. However, note that sunlight reflected off exterior cladding materials carries all three components at different scales based on material properties. For these reasons, designers must be qualified and account not only for all factors mentioned here but also for different criteria to meet building code, industry standards, design intent, and desired performance. The building context and intended use, play a major role in the overall outcome.

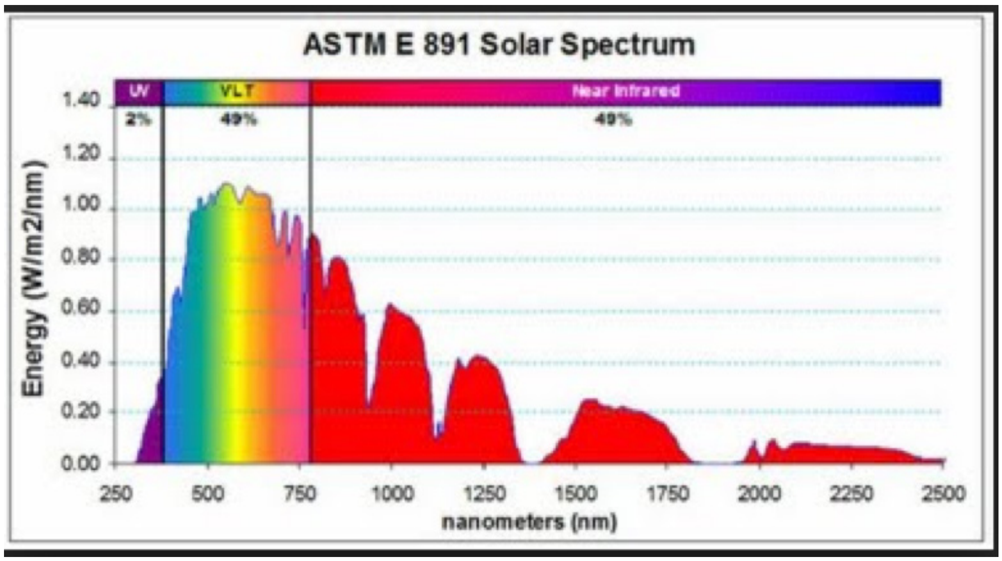


Figure 2. Solar Spectrum

Science of Focused Reflective Solar Energy

Environmental and Geographic Features

Environmental conditions and geographic features play an important role in how both direct and reflected solar energy can affect building cladding materials and fenestration components. The first consideration is to understand solar geometry and how it changes throughout the year. Direct solar radiation is dependent on the sun's angle and geographic location on the earth. The peak solar irradiance in the US for a surface perpendicular to the sun is typically between 250 and 350 Btu/hr*ft2 (800-1100 W/m2) and occurs when the sun is highest in the sky. The solar energy incident on a receiving surface is highly dependent on the orientation of that surface relative to the sun. As the angle between the sun and the receiving surface increases the effective solar exposure is reduced. Normally for a high summer sun, low solar irradiance occurs on a vertical surface at mid-day and high solar irradiance occurs on a vertical surface shortly after sunrise for an east facing location and just before sunset for a west facing location. For a low winter sun, high solar irradiance occurs on a vertical surface usually at mid-day for a south facing location.

Almost as equally important as direct solar radiation is reflected solar radiation. A percentage of incident solar energy is reflected from all exposed building materials. For most common building materials, the reflection is effectively diffused in all directions because of optically rough surface characteristics (Reagan and Acklam 1979). However, on smooth surfaces such as window glass, accumulated snow and swimming pools, the reflection is direct, and its path is determined by the angle between the line normal to the glass surface and the earth-sun line (a combination of the solar azimuth and solar altitude), called the incident solar angle. There could also be an accumulative effect where surfaces can receive both direct and reflected solar radiation. Refer to Figures 3, 4 and 5.

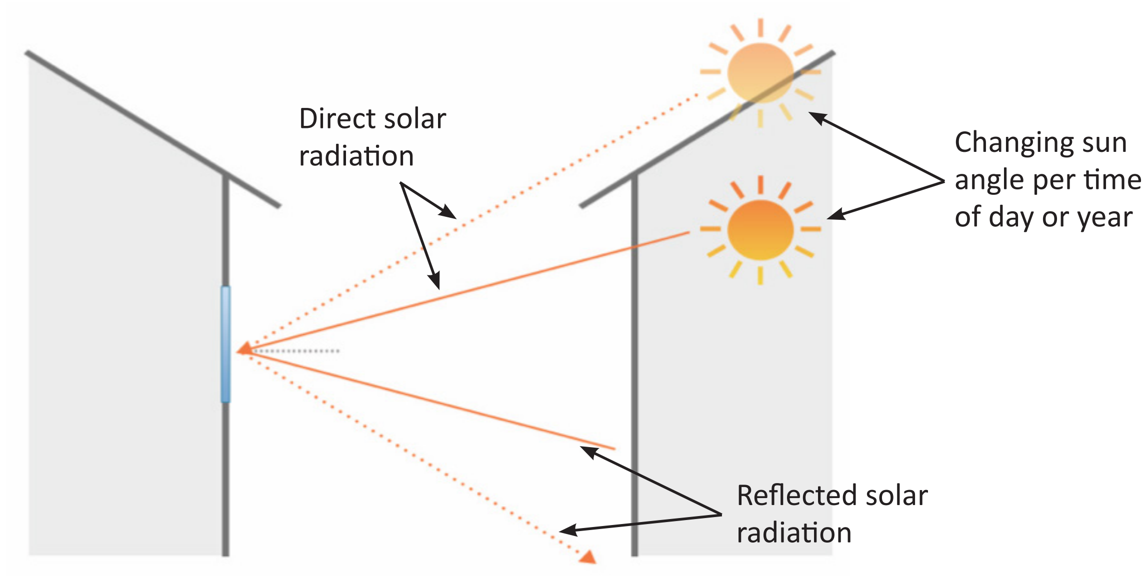


Figure 3.
Elevation view of representative solar radiation geometry for neighbouring structures. Angle of the sun can play a role in how much reflected solar radiation is reflected onto adjacent surfaces.

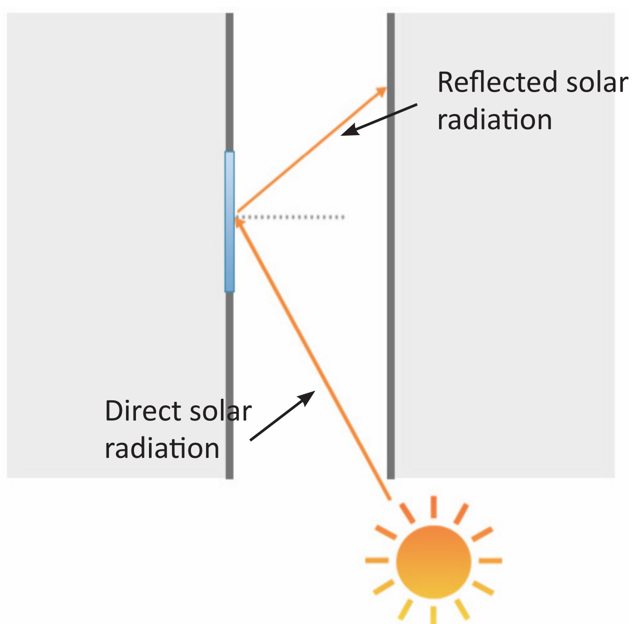


Figure 4.
Plan view of representative solar radiation geometry on parallel walls, representative of neighbouring structures.

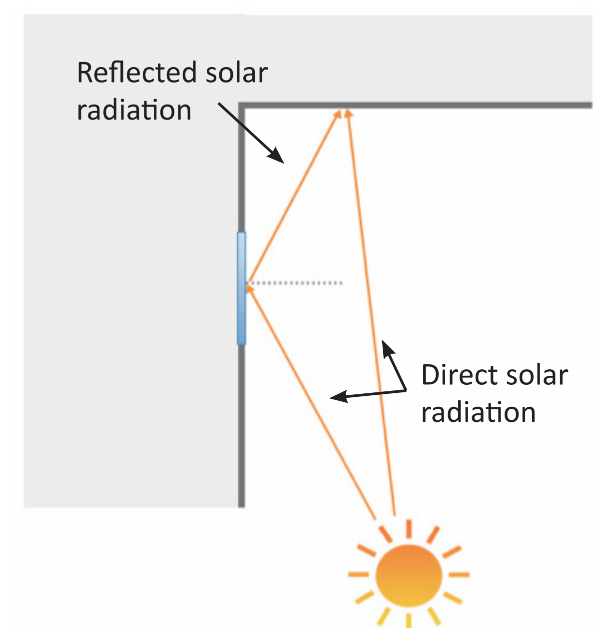


Figure 5.
Plan view of representative solar radiation geometry on perpendicular walls, representative of an alcove on the same structure.

All environmental conditions play a role in the heat transfer of any receiving surface that could result in material damage. Variables other than direct and reflected solar radiation could impact the amount of heat transfer of a surface, such as:

- Architectural design such as alcoves, overhangs, inside corners and other features may block wind or trap heat that could affect a surface temperature.
- Local climate conditions such as wind speed and air temperature can affect the heat-transfer rate of a surface.

- Physical obstructions such as foliage, fences, or adjacent structures may block direct or reflected solar radiation from reaching a surface.
- Long-wave radiated energy received as re-radiated heat from nearby surfaces such as asphalt may increase the temperature of a surface.
- Proximity of alternate heat sources to the surface that could provide direct or reflected radiation such as air conditioner compressors and barbeque grills.
- The ability of a surface to be affected by the amount of received direct and/or reflected solar energy combined with any additional long-wave radiation or contributing environmental factors is related to its physical properties. Building materials with temperature resistance > 250 °F will fare best in most applications.

Architectural Features

Various architectural features of building cladding materials and fenestration components could influence the degree of how it would reflect solar energy. As mentioned earlier, the smoothness of a reflecting surface plays a role in the ability for direct solar radiation to be more fully redirected to another surface. Rough surfaces such as painted walls, patios, sidewalks and driveways still provide a diffused reflection onto adjacent materials. The color of a reflecting or receiving surface can also influence the effect of reflected solar energy. Darker colors will tend to absorb more solar energy rather than reflect it and vice versa, light colors could reflect more solar energy than they absorb.

Many building cladding materials and fenestration components are designed to reflect solar energy to either provide better performance, specific appearance characteristic or improved longevity. These types of products could provide for more direct reflected solar energy to adjacent materials. Building materials such as aluminum and copper flashing, brass kick plates on exterior doors, coated and non-coated glass products, aluminum or vinyl siding and painted wood, to name a few, can and do reflect solar energy onto adjacent materials.

Contributing Factors

Environmental Factors

The environment in which the building is located and the incident solar energy influence heat absorption. Depending on the building's geographical location and the time of year, the intensity of solar radiation and the resulting ambient temperature can vary significantly. Furthermore, wind speed and the type of materials used in the local environment also affect the temperature of building materials. As an example, direct and diffuse solar radiation can raise the temperature inside the insulating glass unit (IGU) and affect its level of deflection. The level of solar radiation incident on a surface is defined by the combination of its orientation, the solar azimuth and the solar altitude. At high sun angles (>40°), the type of glass used could have significantly less impact on the reflectance of the IGU.

Environmental factors play an important role in how much heat is absorbed by materials, as well as the flexing and deflection of IGUs. IGUs typically have a sealed gas volume and contain an atmosphere representative of the air temperature, altitude and atmospheric pressure of the manufacturing location in which the unit was sealed. Atmospheric conditions can change regularly meaning the "built-in" air pressure can vary from unit to unit. Of more importance is that when the unit is installed in its intended location, any change in the pressure balance between the sealed internal volume and the atmosphere will result in glass deflection. Therefore, changes in temperature, pressure or elevation will produce some distortion in the unit, which can be considered normal and not necessarily indicative of a defective unit. As an example, when atmospheric pressure increases relative to the sealed interior pressure, the glass can deflect inwards and become concave. The level of deflection depends on the magnitude of change; a 0.5 psi pressure differential is approximately equal to a change in atmospheric pressure of 1” Hg. A temperature change of 20 °F or an altitude change of 1000 feet will also produce a 0.5 psi pressure differential.

Architectural Orientations and Applications

Increasingly complex geometries in buildings in concert with exterior materials selection and height have exacerbated the effect of reflected light from glazed buildings that can range from reflective glare effects to material damage. But one must keep in mind that this phenomenon is not exclusive to large areas of glass. Other building materials like thermoplastic olefin (TPO) roofs and metal panels can produce a similar reflectivity effect.

The main five factors to consider in the design are: building location, building orientation, material selection, building design and exterior building features.

1. Building location

A building’s geographical location is important from the “available day light” point of view. Locations between the equator and the Tropic of Cancer (Northern Hemisphere) and the Tropic of Capricorn (Southern Hemisphere), have a more balanced day/night duration. On the other hand, locations away from the Tropics see a more drastic change in daytime duration around the seasons.

A building’s geographical location also determines the solar altitude angle which can be summarized as the angle between the horizon and the sun. Locations such as New York and London are subjected to low solar altitude angles during the winter. Their 41 degrees and 51 degrees North latitude, respectively, can be a design challenge when trying to keep direct sunlight out of buildings.

2. Building orientation

Building orientation is one of the main factors to consider when trying to address solar reflectivity. It is of common knowledge that south exposure façades are subjected to direct sunlight during the largest part of the day (for projects located in the Northern Hemisphere). However, east and west facing façades need to be carefully studied due to the relatively low solar angle at sunrise (east façade) and sunset (west façade). If properly oriented, even the most challenging building geometries can be accommodated without compromising on solar reflectivity.

3. Material Selection

Material selection plays an important role in the topic at hand. Nowadays, there is a wide variety of materials available and being used in the design of buildings. These materials are now mixed on different building elevations in order to achieve the desired appearance. Some materials are available in different textures and different finishes, some others provide different performance and meet different criteria. But the most important factor to consider in the selection of materials is the building context.

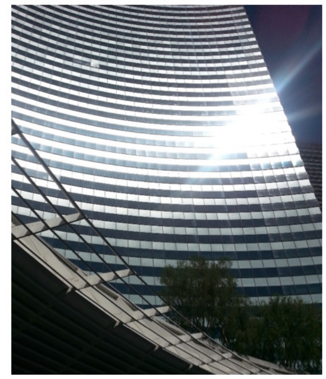
When using reflective or potentially reflective materials, the designer must carefully study the building context and decide what materials serve the intent without compromising performance and final outcome that could be produced by such materials.

Some reflective materials can be treated to become less reflective. Materials like glass are available in a broad pallet that allows the most complex building geometries to be achieved.

4. **Building design**

Building design is what brings all the main factors mentioned above and the minor ones, into harmony. If the building location and orientation are carefully studied, all environmental factors can be designed for and therefore, materials selected properly. There is no single factor to blame in the design of buildings that have gone wrong. Factors mentioned above in combination with building design are the common denominator in cases reported that have unfortunately made the news.

a. **Concave façade**



Concave façades pose a major challenge in the selection of materials as they may focus reflected solar energy. Focusing solar energy can lead to glare and increased surface temperatures at the focused areas. Materials for these types of building geometries need to be properly selected and addressed for the different outcomes they might produce. Special attention must be paid to south facing concave façades since, as mentioned above, they are subjected to the sun's solar energy the majority of the day. Reflective materials on concave façades can exacerbate the end result if overlooked during design.

5. **Exterior building features**

Exterior building features can help mitigate any potential solar reflectivity concern. The features are often times mounted to the façade or can be directly attached to the building structure. Features such as shading devices, fins, and decorative designs can be seen on buildings around the world. Some of these features serve a performance purpose, while others are only aesthetic.

Material Properties and Factors

The ability of cladding materials (siding, brick, stone, etc.) to absorb and reflect infrared radiation varies depending on several factors:

- Material type – glass, wood, vinyl, brick, stone, metal
- Color – lighter colors reflect more than darker colors; darker colors absorb more than lighter colors
- Surface finish – shiny/glossy finishes reflect more than matte/textured and flat finishes

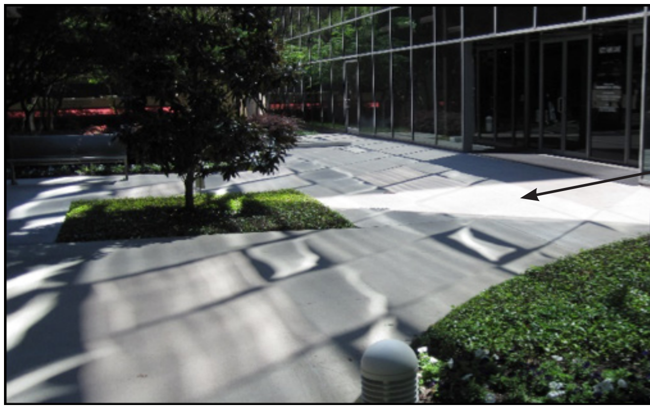
If a concern exists regarding a cladding products exposure to infrared solar radiation (direct or reflected) then the specifier of the cladding product should take these variables into consideration when designing for proper performance and longevity.

Glass Deflection

Light and solar energy incident on glazing will be partially transmitted through the glass, absorbed by the glass and reflected off the surfaces of the glass. The degree to which light and solar energy are reflected are dependent on a number of variables including:

- The angle and orientation of the sun to the surface of the glazing
- The flatness of the glazing
- Coatings on the glass

Perfectly flat glass will reflect light and solar energy. Glass may deflect due to a variety of environmental factors (see section below) that may lead to the concentration of this reflection in a localized area. Such deflection can occur in monolithic glazing systems but it is more typical of insulating glass. When an IGU becomes concave where the gap between the lites at the center of the unit becomes less than the gap at the edge of the unit reflected light may be concentrated at a distance known as the focal length. The concentrated effects of the reflected solar energy can adversely affect the surfaces it is cast upon due to added heat from the increased intensity.



Reflection of light from insulating glass unit deflection.

The effect of the environmental factors on glass deflection can be influenced by a number of design considerations:

- Glass thickness: thinner glass will deflect more easily than thicker
- Glass type: whether heat strengthened, tempered or annealed, all glass types will deflect the same
- IGU unit size: large IGUs will deflect more easily than smaller units
- IGU aspect ratio: the ratio of the height to width or the width to height of the IGU can affect glass deflection. Aspect ratios closer to 1:1 (a square) will have greater deflection than units with higher aspect ratios.
- IGU cavity gap: units with a greater distance between glass lites that define the cavity gap ("airspace") will have greater deflection than units with narrower gaps.

Design Considerations to Reduce Reflectivity

This document addresses some, but not all, of the possible design considerations that could help minimize the negative impacts of solar reflection. The following design considerations are some of the possibilities to reduce the effect of solar reflection:

Building Design Considerations:

1. Consider using building materials that have a high temperature resistance (able to resist temperatures >250 °F).
2. Be aware of building areas of high risk for solar reflections and determine if any building materials in the vicinity will contribute to increased heat gain on other building surfaces. Walls with highly reflective surfaces that are directly opposite other walls, or inside corner details should be evaluated. Other areas include alcoves and overhangs.
3. Be aware of building orientations and how direct solar radiation will potentially reflect off of the building surface when facing south, east and west.
4. Be aware of how the use of trees, fences, foliage and other landscape designs can reduce direct sunlight onto reflecting building surfaces.
5. Be aware of curved walls or concave façades that may have a concentrating effect of any reflected solar radiation.
6. Be aware of how building features such as shading devices, fins and decorative designs can affect solar radiation reflectivity.
7. Be aware that features near a building such as swimming pools, accumulated snow and concrete can reflect solar radiation and contribute to the amount of solar radiation encountered by the building surfaces.

Glazing Considerations:

1. For residential windows and doors, choose NFRC-certified products, where possible. These are required to meet tolerance criteria for reduced insulating glass gap dimension at the point of manufacture.
2. Capillary tubes have been used to control the flatness of the IGU, but they may negatively affect thermal performance and shorten IGU life. Special considerations should be taken for their use.
3. Be aware of how glass thickness, IGU size, aspect ratio and cavity gap dimension can affect the ability of an IGU to deflect easier with barometric and temperature changes.
4. Be aware that all glazing options (both coated and uncoated) will reflect solar radiation to some degree. Other cladding materials and adjacent surfaces could have similar (or worse) reflective characteristics.

References

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