Project: Several buildings with curved walls (in LA, Vegas, London) have been accused of causing sunburns and other damage by focusing the sunlight; is it possible?

Abstract

In recent news stories, the architectural designs of various buildings have been accused of causing damaging effects. For this research project, our aim is to investigate whether these claims could be mathematically possible, and, if so, how. We have created several diagrams to demonstrate how the sun's rays and their reflections act as vectors and show how these light vectors can center at a specific focal point. In addition, we have derived and used equations to determine how much heat these reflected light rays can cause so that we can infer whether a concentration of these lights rays could actually generate a high enough heat intensity to result in extreme effects such as those reported, like sunburns or melted cars. We then speculated which building designs would be good candidates for this effect before finally concluding which design would be optimal if one wanted to construct a "death ray" hotel.

Reflections from Buildings Can Potentially Cause Sunburns and Other Damages

To begin the project, we had to determine which shapes of buildings can cause sunburns – or perhaps even fires – most effectively. So, we began by examining real life examples. First, we researched the Vdara hotel in Las Vegas which reportedly caused patrons by the pool to receive sunburns due to the sun's reflections off the hotel's surface. Then we observed 20 Fenchurch Street, nicknamed the Walkie Talkie building, in London which reportedly caused a car in its proximity to catch fire and melt. Although both were designed by the same architect, Rafael Viñoly, these two buildings have different shapes; the Vdara Hotel has a single-shaped curve repeated vertically and the Walkie Talkie building has a paraboloid design.

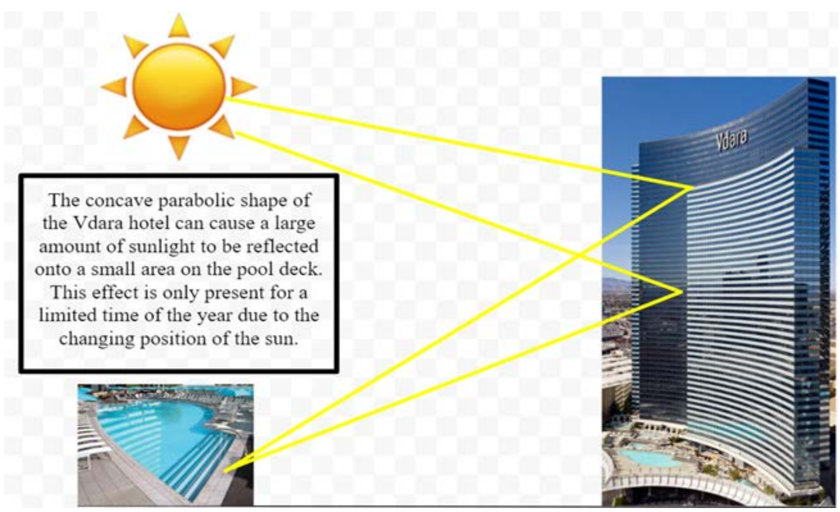

Figure 1: This graphic, featuring the Vdara Hotel in Vegas, shows sun rays reflecting off the building toward the pool area.

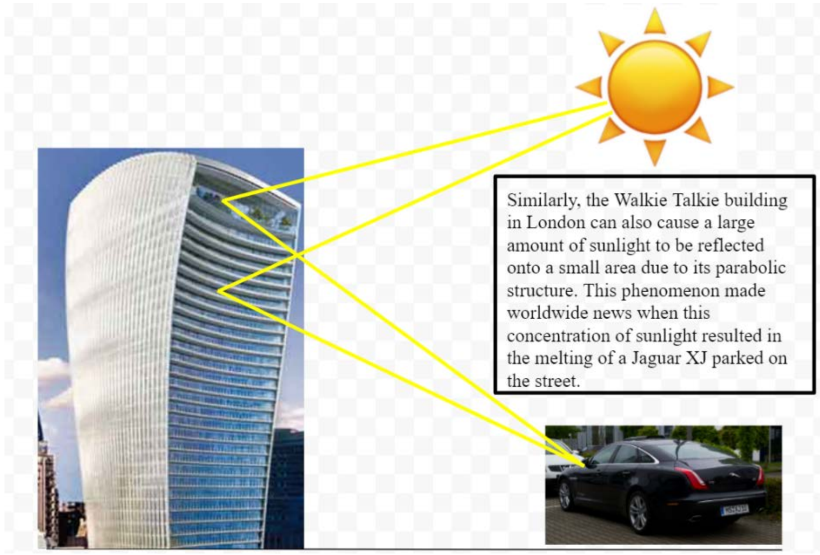

Figure 2: This graphic shows the Walkie Talkie building in London which has a paraboloid shape and allegedly caused a car to melt.

To prove which shape is the most effective in relation to burning, we used NX software to design models of each candidate shape and plot vectors to determine if they all intersect at the same point. Since we were just beginning to brainstorm, we decided to think in the simplest terms possible; this led us to think of sun reflectors that people from the mid-20th century – and even still today – use for sun tanning. The users claimed that it helped them get better tans; however, it also proved to increase their likelihood of becoming sunburnt. The sun reflectors held a rough paraboloid shape, much like the buildings discussed above. This suggested to us that reflections of sun rays off certain shapes can indeed cause damage. Since sun reflectors near a person are able to cause a sunburn, then a building, which is much larger compared to the reflector, could potentially be able to cause not only sunburns, but melting as well, like reported in London with the Jaguar XJ's melted aluminum body.

Figure 3: A woman using a sun reflector for tanning purposes. Note the paraboloid shape.

Our first step in proving these surfaces can cause burning was calculating the amount of energy needed to cause a sunburn. For this, we used the wavelength known for UVB rays. We used UVB rays because it is scientifically proven that these are the rays that cause sunburn. Our calculation is as follows:

Using the equation for Energy $E=\frac{hc}{\lambda}$

Where h (Planck's constant) = 6.626×10^{-34} J·s

c (speed of light) = 3.00×10^{8} m/s

λ (lambda) = 305 nm

Lambda was obtained by averaging the range of the UVB wavelength (290 nm – 320 nm)

Therefore,

$E_{photon}= \frac{(6.626*10^{-34})(3.0*10^{8})}{3.05*10^{-11}} = 6.91738 * 10^{-19}$ J

This is the amount of energy contained in a single beam of light that would be reflected. To simplify things in the context of our project, we considered a standard sun reflector that has three faces. The three faces reflect three beams of light that each contain $6.91738*10^{-19}$ J/photon of energy. So, a three-faced reflective mirror would have $3(6.91738* \ 10^{-19})$ J/photon of energy focusing on a single point. Figure 4 shows a parabola with 10 light reflections, so this would have $10(6.91738*10^{\wedge-19})$ J/photon focusing on a single point. This is 3.33 times the amount that it takes for an individual to tan. Although the exact number of reflective surfaces on the buildings in context could not be found, they clearly have much more than ten panels. If we suppose that they have 100 reflective panels on a side, then the amount of energy focused at a given point would be 33.3 times the amount of energy required to tan a person. We assume that this is enough to sunburn an individual.

After determining the amount of energy per photon needed to potentially cause a sunburn, we explored various shapes in order to determine which structures could concentrate enough sunlight to reach this threshold. First, we supposed that a concave spherical construction, similar to a lens, might be sufficient.

Concave Spherical Construction

The first shape we considered was one with a concave spherical shape. This was the most basic form of the lens shape that we could think of, so we wanted to determine to what extent this base shape focuses light, so that we may show the ability of the shape to cause burning when light rays are reflected off it. To achieve this, we plotted multiple vectors that represent the light rays reflecting along the curve of our sphere to see if the points would intersect at the same point. The following image is our model of this.

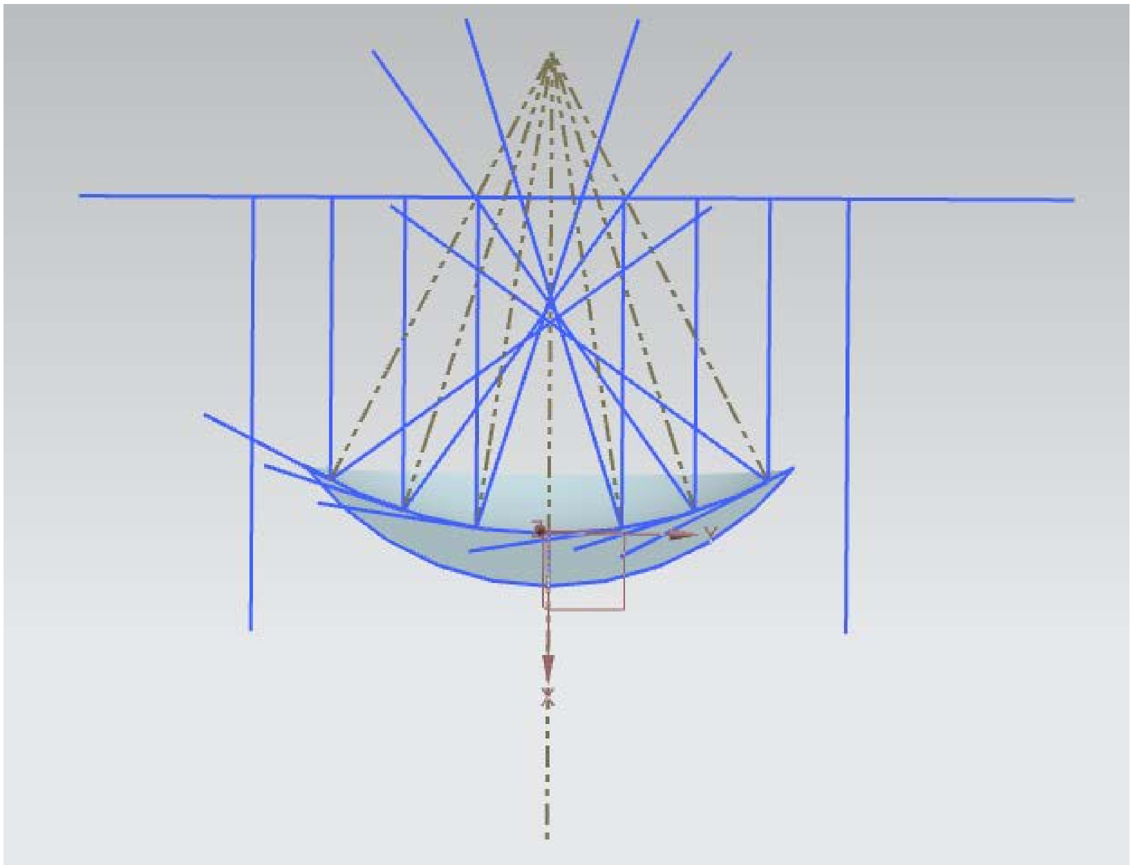

Figure 4: Model of a concave spherical shape.

As shown by the model above, the reflections of the light rays do not intersect at one point, meaning it is not very effective at causing sunburns and other damages due to light reflection. This inconsistency in intersection is due to spherical aberration. Spherical aberration is an optical problem that occurs when the light rays focus at different points after passing through a spherical shape. Because of this, light rays closer to the ends of the model converge at a shorter distance in comparison to those toward the center of the model. To rectify this issue, architects of lenses, and even headlights, have instead used a paraboloid shape as parabolas do not experience spherical aberration, so this is what we considered next.

Parabola

To model a parabola, we used the equation $y = \frac{x^2}{20}$. The reflected light rays intersect at a single focal point five units from the origin, or midpoint, of our proposed building. Since the building is actually in $\mathbb{R}^3$, it will have multiple midpoints which extend vertically downward along the surface. The following graphic shows how these vectors all intersect at the same point.

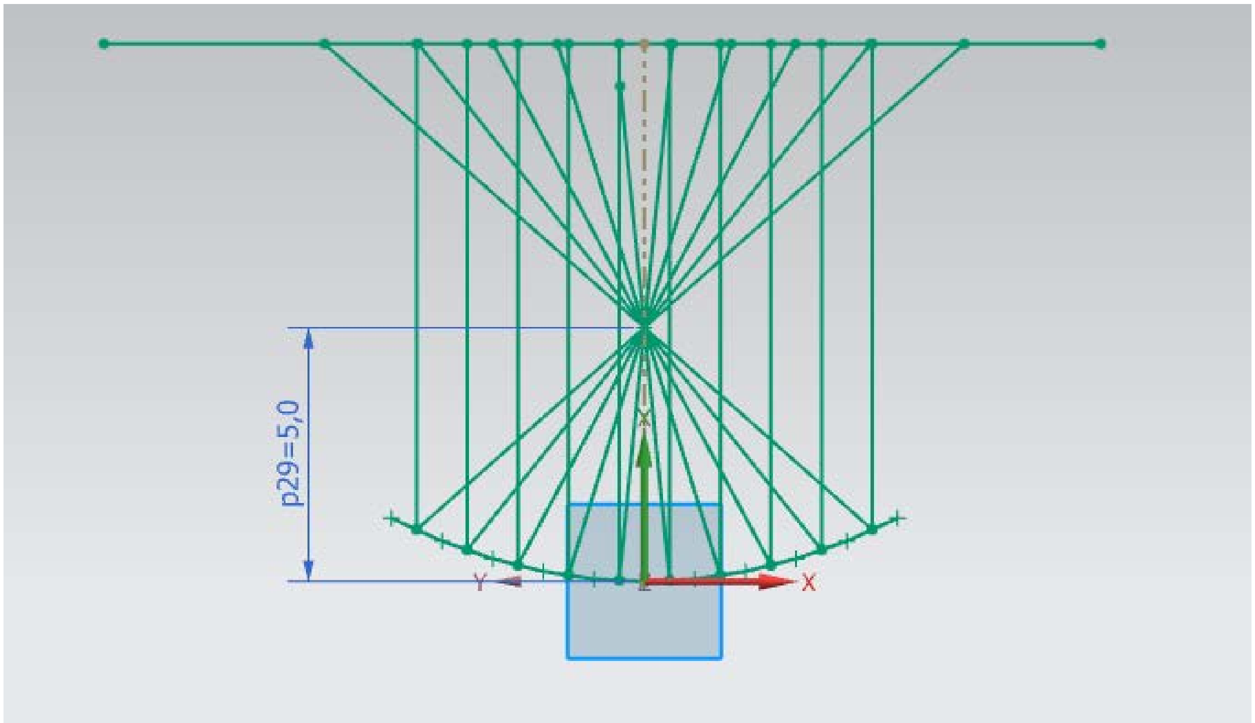

Figure 5: A parabola containing vectors that all focus at one point

The fact that the points all intersect at the same focal point means that this shape will more efficiently burn objects in its proximity in comparison to a concave spherical shape as all of the light, and thus heat, energy is concentrated in one small area. This explains why the buildings in London and Las Vegas were able to cause damage. As aforementioned, the focal point of this shape meets five units from the origin. This value was found using the equation of a focus, that is the focus = $\frac{1}{4a}$. In this case, given the equation of our parabola was supposed to be $y = \frac{x^2}{20}$ the value for a is $\frac{1}{20}$.

After considering the differences in these designs, we developed a better understanding of why the Walkie Talkie building and Vdara hotel had such suitable conditions for centralized reflection. The Walkie Talkie, however, is the building we believe has the optimal design as its 3D paraboloid shape allows all light rays to intersect at one singular point due to its multiplicity in curvature. The Vdara hotel, although still effective in burning, is not as powerful as the Walkie Talkie building because it just features stacked uniform parabolas. This means that on each level of the hotel, its individual vectors will meet at a single point. However, all the light rays in all of the levels will not meet at the same point; instead, they will vary by height and also appear stacked, in the form of a line segment, as shown in the picture below.

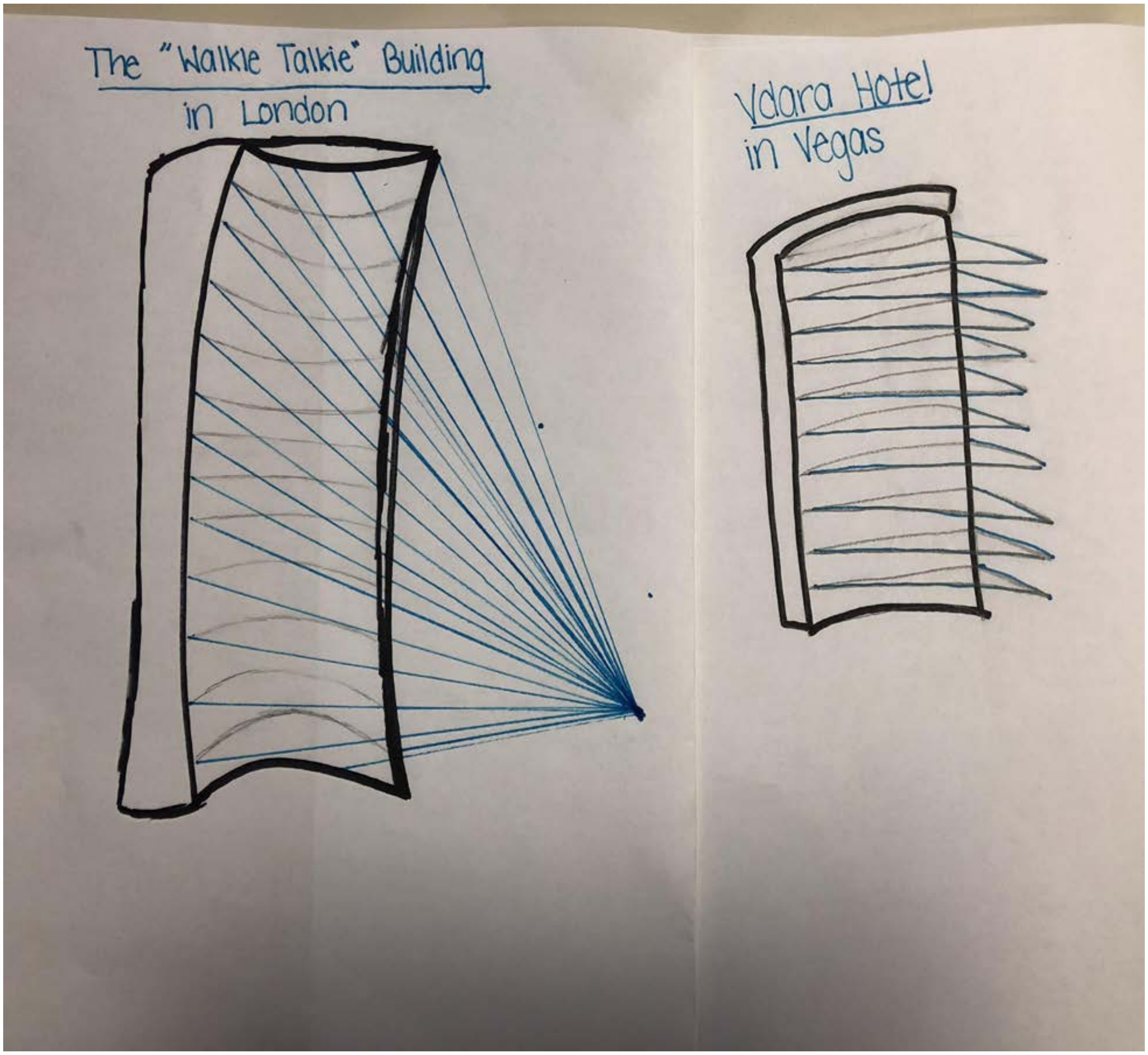

Figure 6: This is a drawing comparing the vectors representing the reflected light rays for each building design.

Moving forward, we wanted to determine a function for the intensity (I) of light for the paraboloid to show how the intensity of light increases as it moves toward the focus and decreases as it moves away. To do this, we noticed that all the light coming into the shape holds the same amount of energy (E), meaning, as it's reflected, every horizontal section of reflected light has the same energy. We wanted a formula with respect to y of the intensity of the light where I equals the total energy of the surface of the shape over the area of the cross section of the reflected light at a given y value. Assuming it is the shape as in Figure 7 with a domain [-5,5] and a focus of (0,5), the x coordinate can be found using the line from point (0,5) to (5,0), which has the equation $y= -x+5$. Each cross-sectional area (A) of the reflected light was determined using the equation of the circle $y=\pi r^2$, where r is equivalent to x. Now that we had the function of the cross-sectional area and the function giving x as a function of y, we composed the function of the area with respect to y as $A(y) = \pi(5-y)^2$. Since we derived that the energy of each y coordinate is equal, the function of energy with respect to y is simply E for the total amount of energy as it is not dependent on y; it is constant. Furthermore, if $I = \frac{E}{A}$, then I(y) is the function of energy divided by the function of area with respect to y. Thus, $I(y) = \frac{E}{\pi(5-y)^2}$. This equation can be used to show how intense the light is at the focal point of the vectors, which can, subsequently, explain how burning and other extreme effects can occur.

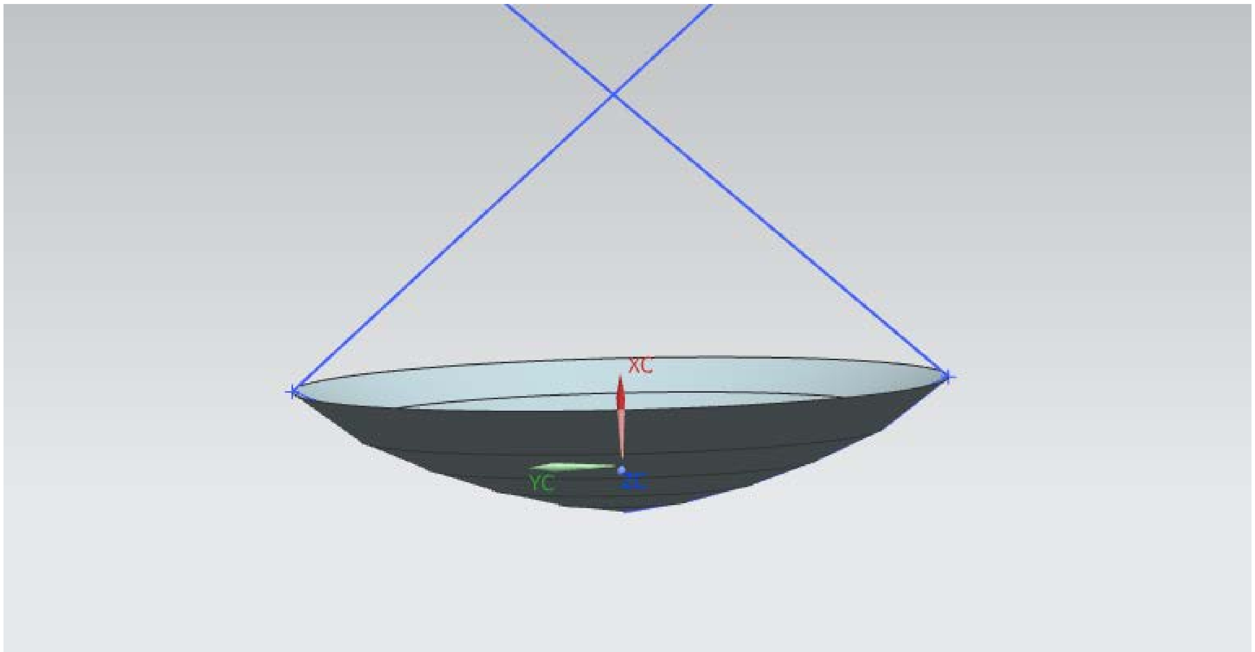

Figure 7: This is a graphic of a negative paraboloid which we used to find the equation for I(y). The values used to model this are the same as those in Figure 5. The intersection of the blue vectors is the computed focus.

Conclusion

In conclusion, we have determined that it is indeed possible for buildings with curved walls to cause sunburns and other harmful effects; however, very specific conditions must be met for this to happen, which is why even though it is possible, it is highly unlikely. These buildings must have an architectural design which causes the reflected light rays to meet at the same focal point in order to concentrate enough energy to cause these damaging effects. Therefore, the news reports claiming that buildings allegedly caused burning damages cannot be discounted; however, the reason as to why these burnings do not regularly occur is due to solar convergence, which refers to regions of extremely high energy density or temperature. These can occur due to the position of the sun and, according to the Hotspot Effect, the sun is only in position for this optimal energy density for two to three weeks per year and roughly two hours a day on these days. This should only produce a negative effect if a building has a parabolic construction which forces reflected light rays to meet at one focal point as, otherwise, the concentrated energy would not be intense enough to cause any real harm.

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Images obtained from gettyimages.com

All models created using NX Software, Google Drawing, or by hand.

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