International Journal of
Science and Engineering Investigations
vol. 7, issue 79, August 2018
ISSN: 2251-8843

Self-Shading Impacts of Single and Double-Curved Building Façade Panels

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Abstract- The use of single-curved and double-curved panels in building facades has been seen in many prominent examples. In addition to aesthetics, these panels can potentially provide environmental benefits through the self-shading created by their shape. This paper uses simulation modeling to quantify the reduction in incident solar radiation for geometries with these panels, for different locations across the mainland United States.

Keywords- *Building Facades, Insolation, Complex Facades*

I. INTRODUCTION

A number of recent building designs incorporate the use of single- and double-curved panels to create complex façades. Some prominent examples include the IAC Building in New York City, USA (Figure 1); the BMW Center in Munich, Germany (Figure 2); and the Sage Gateshead in Newcastle, UK (Figure 3).

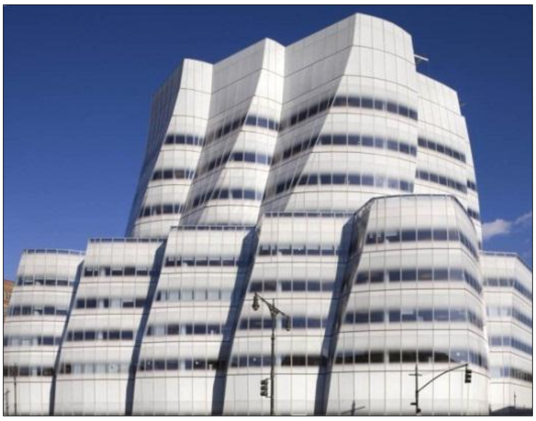

Figure 1. IAC Building in New York City, New York, USA

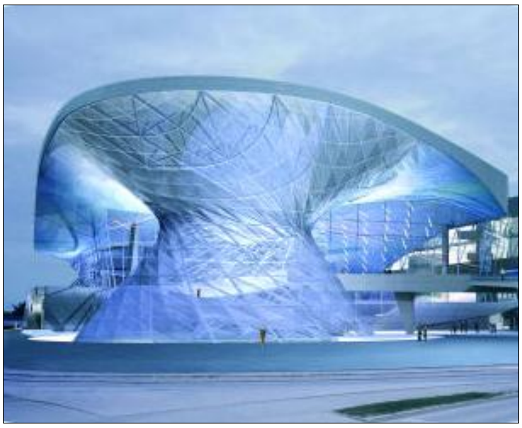

Figure 2. BMW Center in Munich, Germany

Figure 3. Sage Gateshead building in Newcastle, United Kingdom

The emergence of digital modeling and fabrication techniques have greatly eased the challenges faced in manufacturing single- and double-curved panels (Figure 4), however, their use is still relatively new in construction, and can represent a much higher initial cost as compared to a standard flat panel [1].

Therefore, it would be useful to investigate and quantify whether the use of double-curved panels could provide other benefits that could potentially offset the higher initial costs.

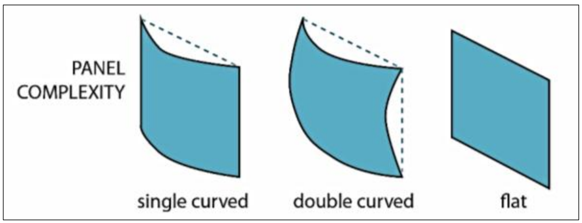

Figure 4. Image showing types of panels used for façade construction. From L to R: single-curved, double-curved and flat panels

One potential benefit that the use of single- and double-curved panels offer is providing self-shading of the building facade. It is seen that the load type most often associated with energy consumption is the climate-driven load imposed externally on a building because of the ambient temperature, solar radiations, humidity and wind [2]. Among these, solar radiation is an important factor, and is typically controlled using appropriate building forms and orientation, and/or through the use of shading devices. Curved building facade geometries, if appropriately shaped, can offer self-shading abilities (Figure 5). The self-shading created reduces the penetration of direct solar radiation into the building, in turn potentially reducing its energy usage.

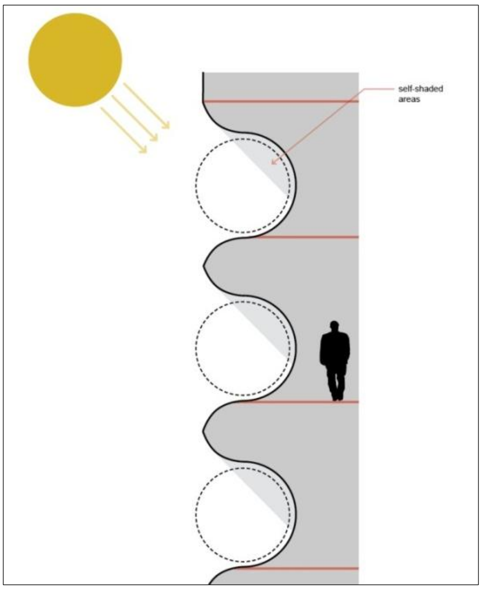

Figure 5. Self-shading created by a façade with double-curved panels

The amount of self-shading created is dependent on the depth of the panel curvature, and the overall geometric shape of the facade. A detailed study of the self-shading benefits of two geometries constructed using single-curved and double-curved panels with channels along the horizontal direction was carried out. This was done using computational simulations of insolation (a measure of solar radiation energy received on a surface in a fixed period of time) within different climatic conditions.

II. EXPERIMENTAL SETUP

The goal of these experiments was to quantify the amount of self-shading provided by calculating the reduction in the total insolation on the surface.

Five different locations were chosen from large urban centers located in the five climatic zones in the continental United States. The US Department of Energy definition of climatic zones, based on the number of heating and cooling degree days was used (Figure 6). Degree days are measurements used to quantify the demand for heating and cooling energy in buildings. The solar radiation maps for the location are shown in Figures 7 & 8. The rationale behind choosing this is to enable designers to understand the behavior of the doubly-curved geometries within the individual climatic zones. By understanding the reductions in the incident solar radiation on the surface, the influence of the shape on the energy use can then be estimated for specific building designs. In each of these zones, one major urban center was chosen as the site for analysis. The chosen urban centers were Denver, Boston, Washington DC, San Francisco and Las Vegas.

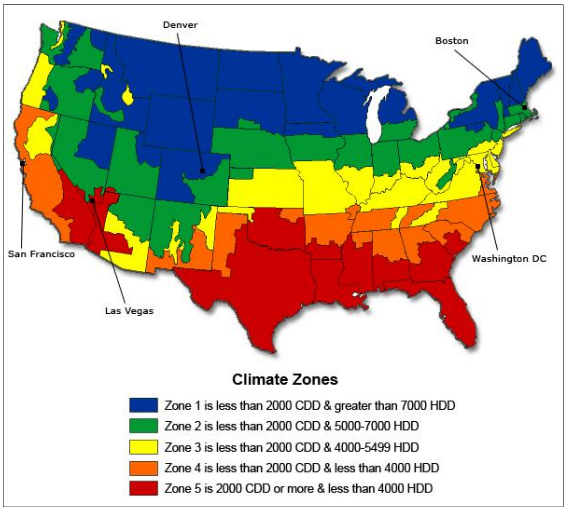

Figure 6. Image showing breakup of climatic zones in the mainland United States, and the different locations used for the analysis

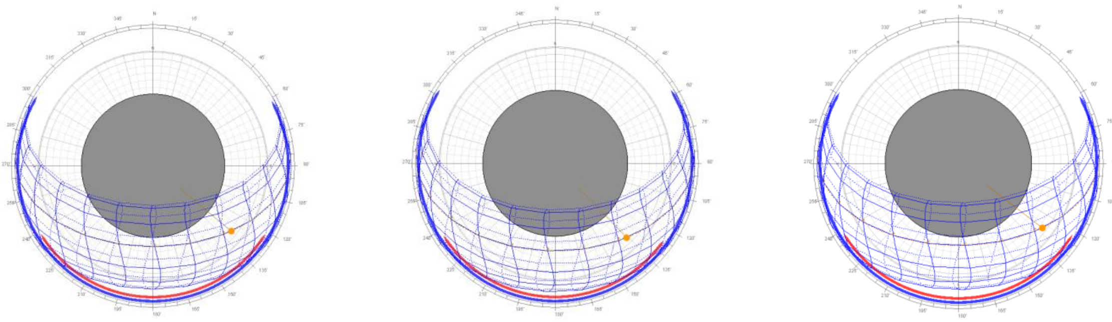

Figure 7. Solar radiation maps for the chosen locations: top to bottom- Denver, Boston, Washington DC

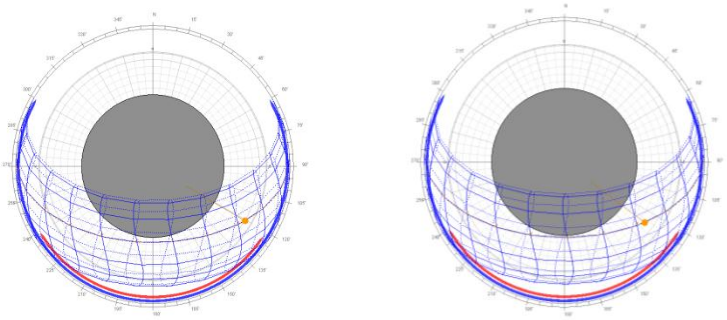

Figure 8. Solar radiation maps for the chosen locations: top to bottom- San Francisco, Las Vegas

Two geometries were utilized for evaluation- one with doubly curved panels (titled “optimal warp”) with a deep channel depth, and a single curved surface (titled “reduced warp”) with a reduced channel depth. These two geometries were in turn compared to a regular cylinder, with a straight surface constructed with flat panels which served as a benchmark. A fixed radius of 20 m. was utilized for all of the geometries. The geometries were created using CAD software, AutoCAD, and imported to environmental analysis software, Ecotect Analysis [4] for the simulations.

A sectional view of the geometries used, showing the channel depth can be seen in Figure 9 below, while Figure 10 shows three-dimensional views of the geometries.

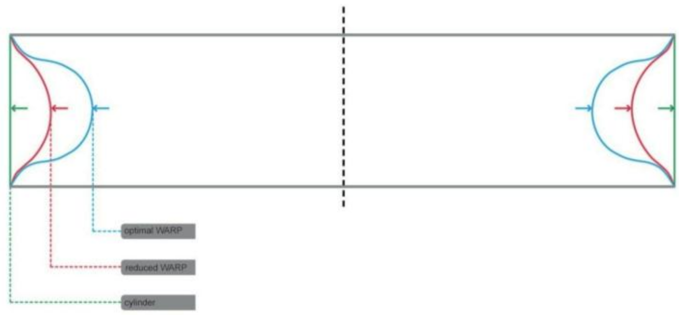

Figure 9. Sectional views of the three geometries utilized for the analysis, showing the respective channel depths created by the panel curvatures

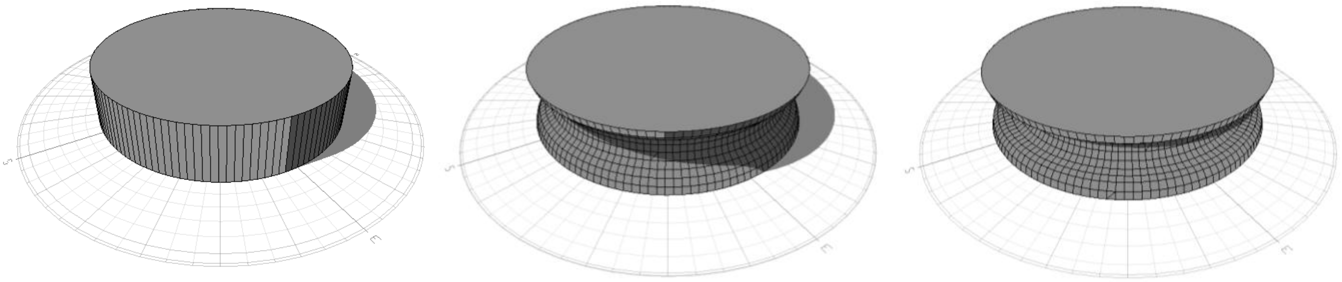

Figure 10. 3D views of the three geometries utilized for the analysis. From top to bottom: a regular cylinder with flat panels, a “reduced warp” with single-curved panels, and an “optimal warp” with double-curved panels

The simulations were carried out to obtain cumulative monthly values of the radiation on the surface, for a period from 8:00 to 17:00 daily. This time range was chosen to reflect the typical usage patterns of commercial buildings. Each simulation was run for one year. A completely sealed building with no natural ventilation is assumed. Default options for mechanical equipment are assumed for calculating energy use.

III. RESULTS

Visualizations of the simulation results for the different geometries, for the respective locations are shown below in Figures 11-15. The visualizations are presented for each surface facing the cardinal directions. The graphs shown provide a tabular representation of the insolation values by month. The insolation is measured in Wh/m^2.

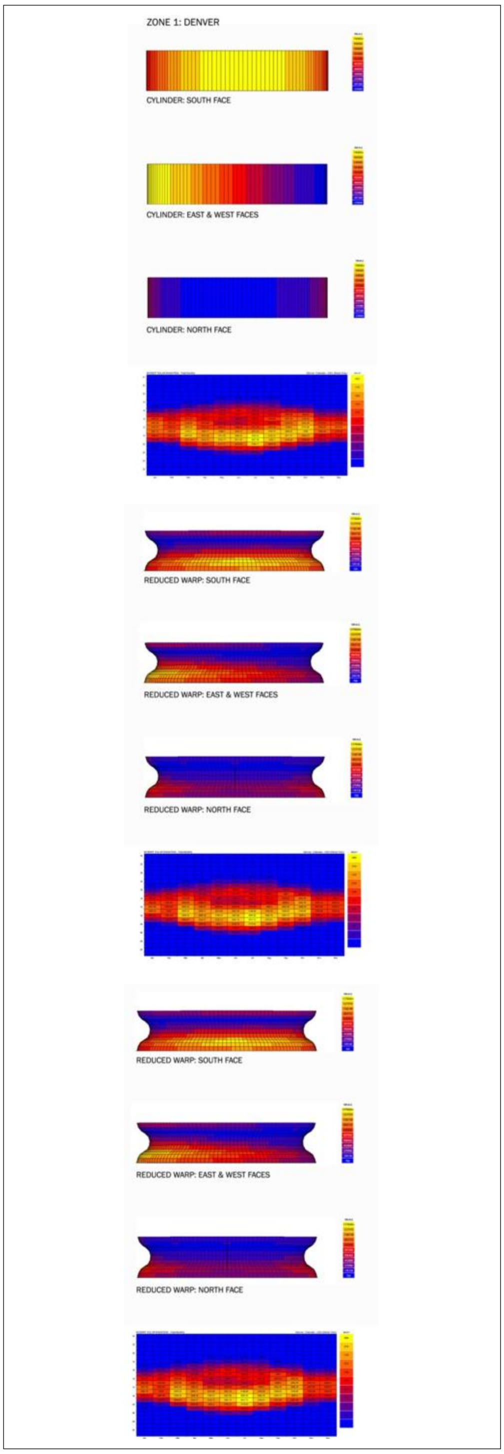

Figure 11. Insolation results for Denver

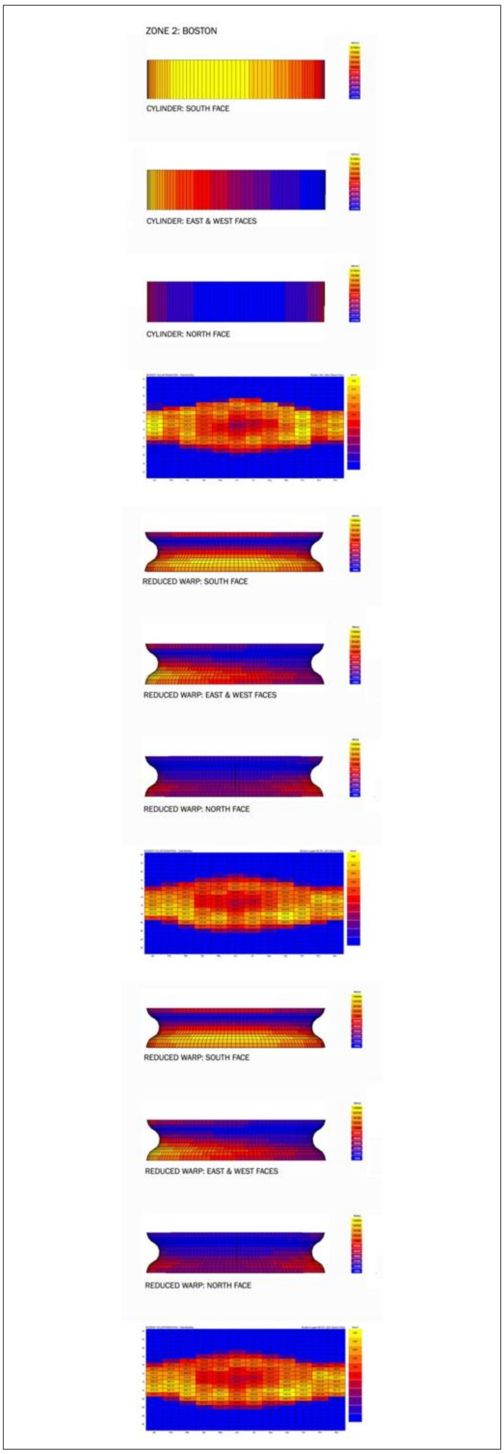

Figure 12. Insolation results for Boston

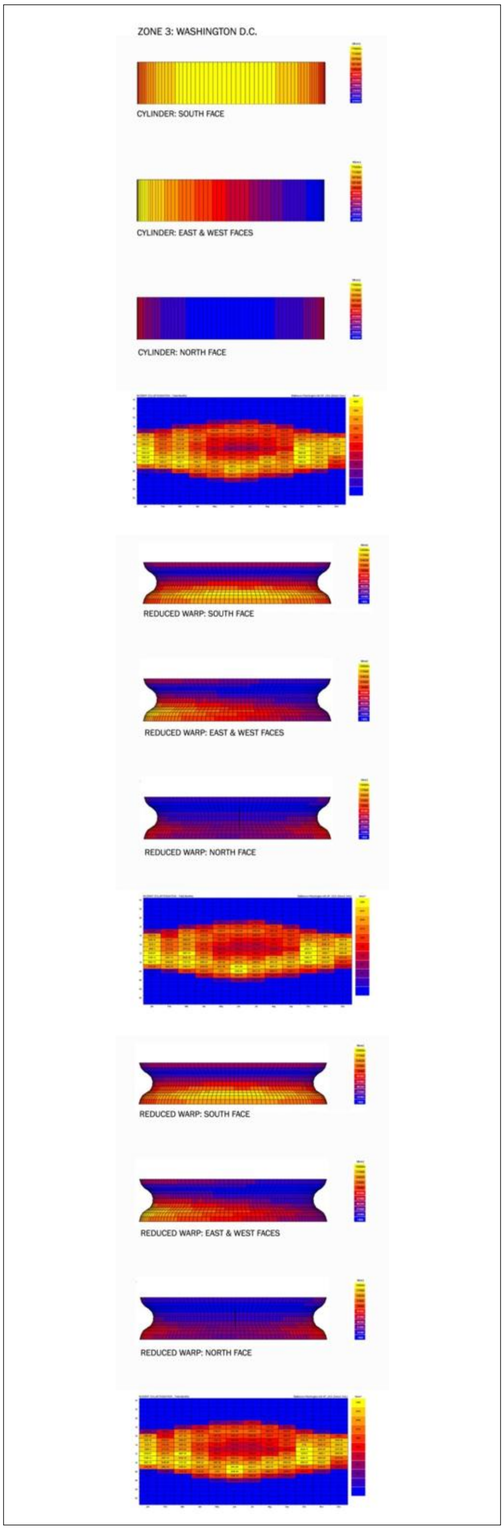

Figure 13. Washington DC

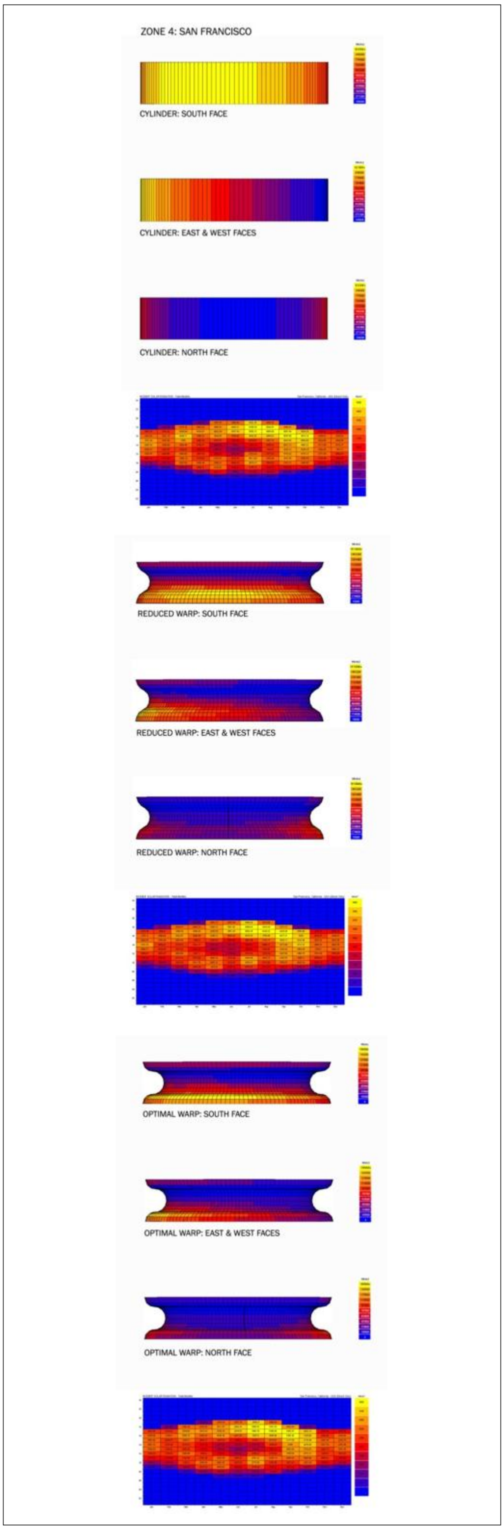

Figure 14. Insolation ersults for San Francisco

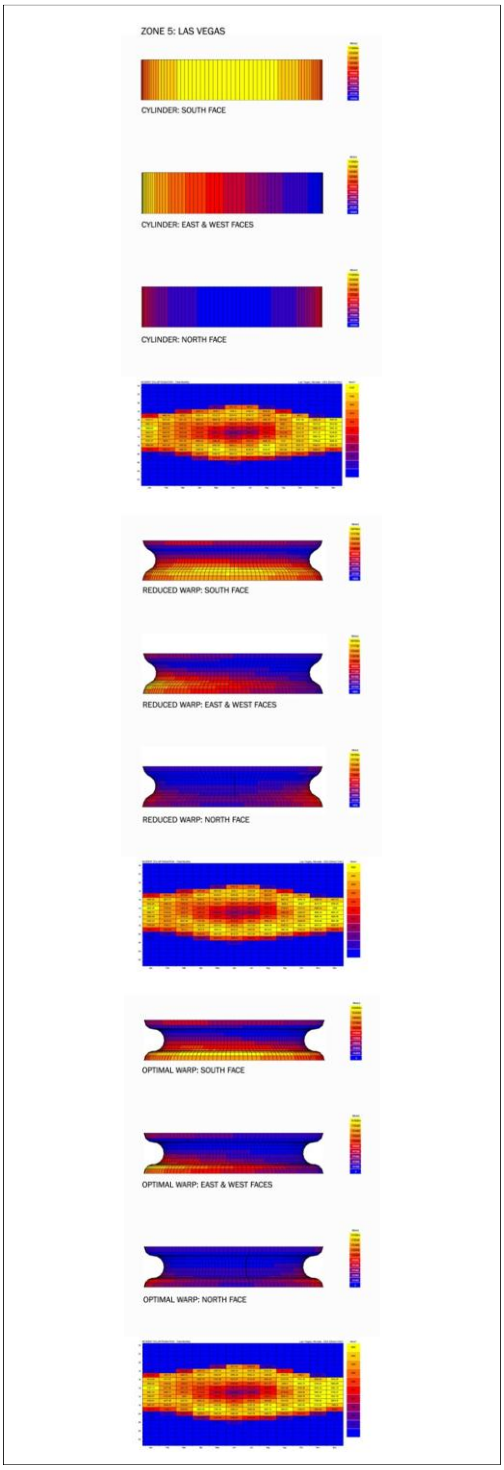

Figure 15. Insolation results for Las Vegas

The data from the simulations was then fed into Excel and graphed to obtain comparisons between variations. The results can be seen in Figure 16.

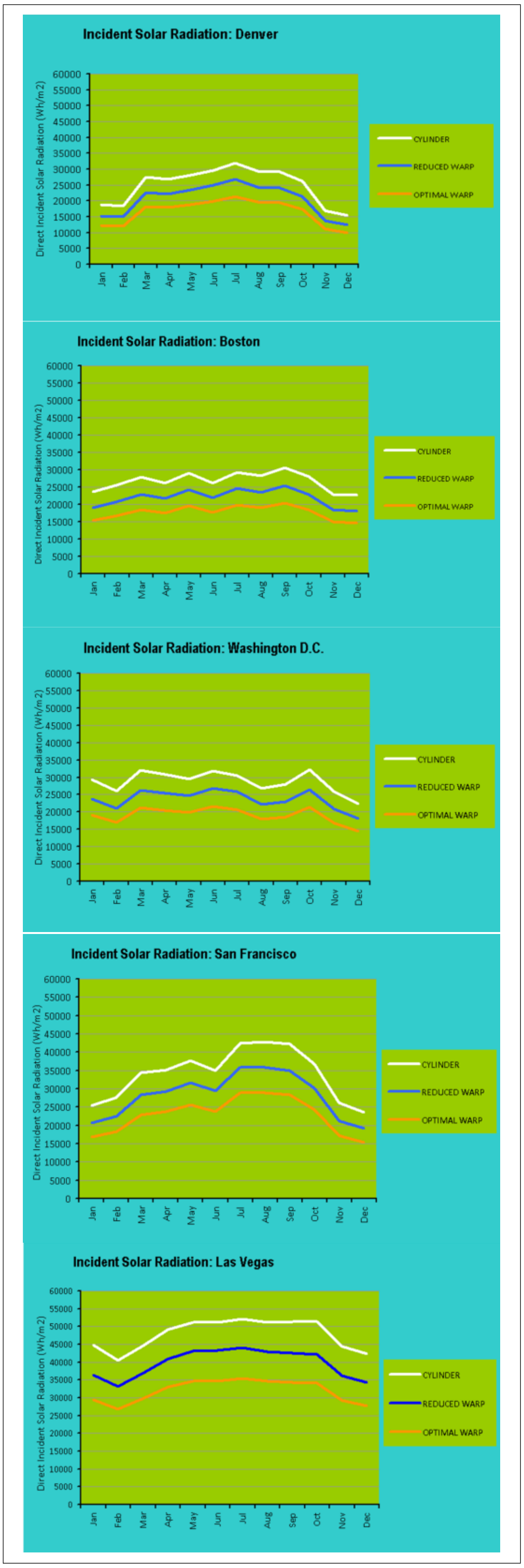

Figure 16. Insolation results for each geometry analyzed graphed by location

The results show that for all the locations, the "optimal warp" geometry with the double-curved panels offers an average reduction of 33.48% in incident solar radiation annually across all locations when compared to the cylinder, the "reduced warp" geometry with the single-curved panels an average reduction of 17.52%, compared to the Cylinder (Table I).

TABLE I. AVERAGE ANNUAL INSOLATION REDUCTION BY LOCATION

Reduction of Insolation Values Compared to the Cylinder		
Location	*Optimal warp*	*Reduced warp*
Zone 1: Denver	-17.62%	-33.72%
Zone 1: Boston	-17.8%	-33.67%
Zone 2: Washington DC	-17.71%	-33.65%
Zone 3: San Francisco	-17.24%	-33.14%
Zone 4: Las Vegas	-17.21%	-33.19%

It is also important to break out the reductions separately for summers and winters (Tables II & III), as envelope heat gain is usually desirable during the winter months for many of the zones.

TABLE II. AVERAGE SUMMER INSOLATION REDUCTION BY LOCATION

Reduction of Insolation Values Compared to the Cylinder		
Location	*Optimal warp*	*Reduced warp*
Zone 1: Denver	-16.41%	-33.00%
Zone 1: Boston	-16.24%	-32.57%
Zone 2: Washington DC	-16.13%	-32.56%
Zone 3: San Francisco	-15.71%	-32.06%
Zone 4: Las Vegas	-15.79%	-32.27%

TABLE III. AVERAGE WINTER INSOLATION REDUCTION BY LOCATION

Reduction of Insolation Values Compared to the Cylinder		
Location	*Optimal warp*	*Reduced warp*
Zone 1: Denver	-18.91%	-34.64%
Zone 1: Boston	-19.57%	-35.00%
Zone 2: Washington DC	-19.09%	-34.70%
Zone 3: San Francisco	-18.77%	-34.33%
Zone 4: Las Vegas	-18.66%	-34.25%

IV. CONCLUSIONS

Two types of geometries utilizing single- and double-curved panels were analyzed in different climatic zones for the reduction in incident solar radiation. The results showed that the geometry with the double-curved panels ("full warp") offers the highest amount of reduction among all the different types.

While self-shading can offer important benefits in some contexts (e.g. by reducing incident solar radiation in summers), in mixed climates with both significant heating and cooling loads, one needs to evaluate the trade-off with the loss of heat gain in winter months. Therefore, it may be useful to sacrifice channel depth in certain situations, if it has a detrimental effect on the energy loads during the winter period. Hence, the actual impact of the self-shading on the energy use of the building needs to be evaluated carefully based on the specific context.

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Ajith Rao obtained a PhD in architectural sciences from Rensselaer, Troy, New York in 2010, with a concentration in built ecologies.

He is currently a Senior Researcher with USG Corporation in Chicago. At USG, he works at the intersection of architecture, engineering, computation and material science, on developing next generation building materials and systems