Impact of Climate-Responsive Shading System: Assessment of Energy Performance for the Future Adaptation of Houses in Louisiana

YILIN ZHENG
Columbia University/ Louisiana State University

ANGEL ASA
HNTB/ Louisiana State University

VICTORIA LOPEZ
FRONT Inc/ Louisiana State University

SOO JEONG JO
Louisiana State University

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INTRODUCTION

Recently, the risk of extreme heat has increased due to global warming, which has led to further energy use for cooling. This cycle intensifies global warming and heat conditions, emphasizing the urgent need for sustainable building design to mediate heat. Shading devices are an effective building repair strategy to reduce the impact of solar heating and the energy demand for cooling, which may help vulnerable populations by decreasing their energy bill (Hansen et al. 2013). However, traditional static shading lacks adaptability to changing weather (Sharaidin 2014).

Climate-responsive systems offer viable solutions for building retrofit due to their ability to respond to varying environmental conditions. These systems can integrate with photovoltaic (PV) systems, maximizing solar energy harvesting by positioning PV cells at optimal angles. Louisiana's high solar energy potential and air conditioning demands amplify the benefits of these systems; Louisiana households use the highest annual electricity purchases per residential customer in the U.S. at 40.47 kWh/day but receive 4.0 - 4.5 kWh/m²/day of solar energy (DeCarolis and LaRose 2023; Sengupta et al. 2022). Moreover, adaptive solar shading systems, which utilize a solar tracker to follow the sun, may achieve a dynamic high-performance design that adds a unique architectural expression to the building facade with the spatiotemporal behavior of each module (Nagy, Rossi, and Schlueter 2012).

The present study proposes a solar-responsive facade system that uses panels in a diagrid formation with mechanical movement in response to the sun's movement. By utilizing computational simulations, this study aims to investigate how the rotation angle of the panels affects the energy performance of the shading device. The solar-adaptive shading system design enhances the sustainability and resiliency of existing buildings by promoting repair rather than new construction.

METHODOLOGY

To conduct the present study, the authors designed an adaptive solar-responsive shading with rotating 6"x 6" panels in a diagrid pattern. Using a solar tracker with monocrystalline solar cells, the panels dynamically adjust to follow the sun's 180-degree movement. Monocrystalline solar cells generally outperform polycrystalline cells in efficiency of approximately 15.27% and are adaptable in different sizes (Ray et al. 2023). Figure 1 illustrates the dimensions and structure of the proposed system. Figure 2 shows the physical model of the shading system. Figure 3 illustrates a scenario of how the generated energy from the system could be utilized. At the outset, authors developed an inventory of the window sizes typically found in New Orleans' residential typologies, and this data set with the typical window size, existing shading, and the distance to the neighboring houses served as a foundation for choosing the size of the panels. As discovered in the window size inventory, houses in New Orleans typically have small gaps that can limit how far the facade can extend when retrofitting.

To investigate the impact of the panels' rotation axis direction on mitigating heat, three scenarios employing vertical, horizontal, and mixed axes for the rotation of panels were simulated assuming that the motorized system automatically finds the optimized rotation angle. The mixed-axis configuration alternated axes diagonally through the shading system. The simulations assumed the system was installed on a west-facing glass façade of a 20' (W) x 20' (D) x 10' (H) building in New Orleans (29.95° N, 90.08° W). The west orientation contributes to most of the heat gain for this area with a hot and humid climate (IECC zone 2A), therefore, the impact on the tested space could be the most significant. The optimized panel angles were defined for extreme heat conditions during the peak time (June 10 – 16, 3 - 4 PM) when sun altitude is around 60° and azimuth is around 260°. The peak load (kW), mostly from cooling energy demand, was simulated using Rhino and Climate Studio. The simulation results were compared to a baseline without shading.

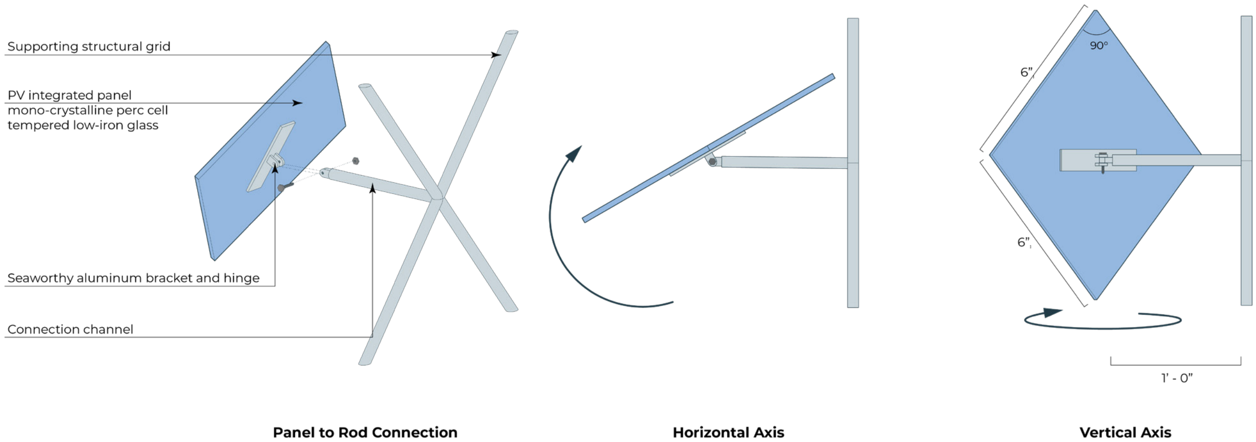

Figure 1. Structure and composition of the tested facade systems. Authors.

Figure 2. Physical model and motion testing of the shading system. Authors.

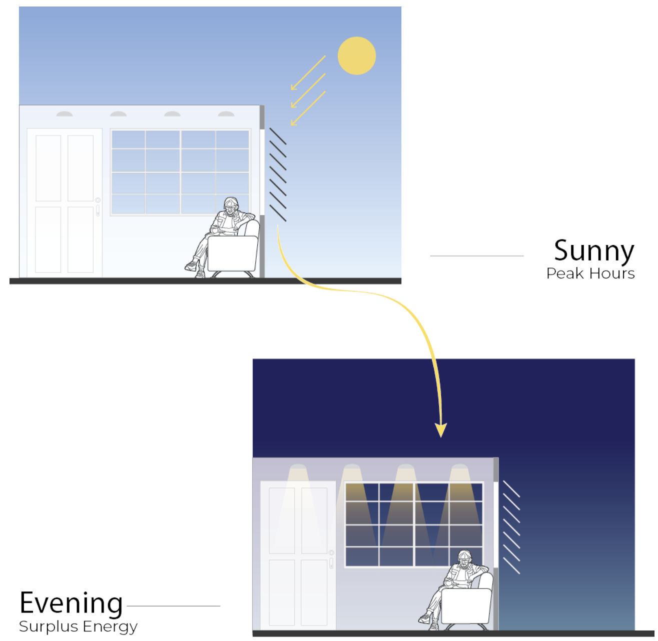

Figure 3. Generated energy use scenario. Authors.

	Baseline (no shading)	Mixed Axes	Vertical Axis	Horizontal Axis
10-Jun	3.36	2.63	3.19	2.24
11-Jun	3.96	3.10	3.79	2.60
12-Jun	4.54	3.65	4.39	3.11
13-Jun	5.42	4.49	5.23	3.94
14-Jun	2.40	2.13	2.25	2.04
15-Jun	3.86	3.13	3.66	2.76
16-Jun	3.86	3.09	3.70	2.66
Mean	3.91	3.17	3.74	2.77
Reduction from baseline		-19%	-4%	-29%

Table 1. Peak energy load for 3 - 4 PM, Jun. 10 - 16 (unit: kW). Authors.

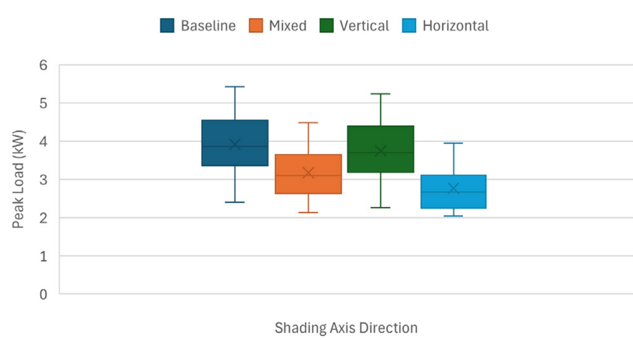

Figure 4. Box and whisker plot of the peak load simulation results. Authors.

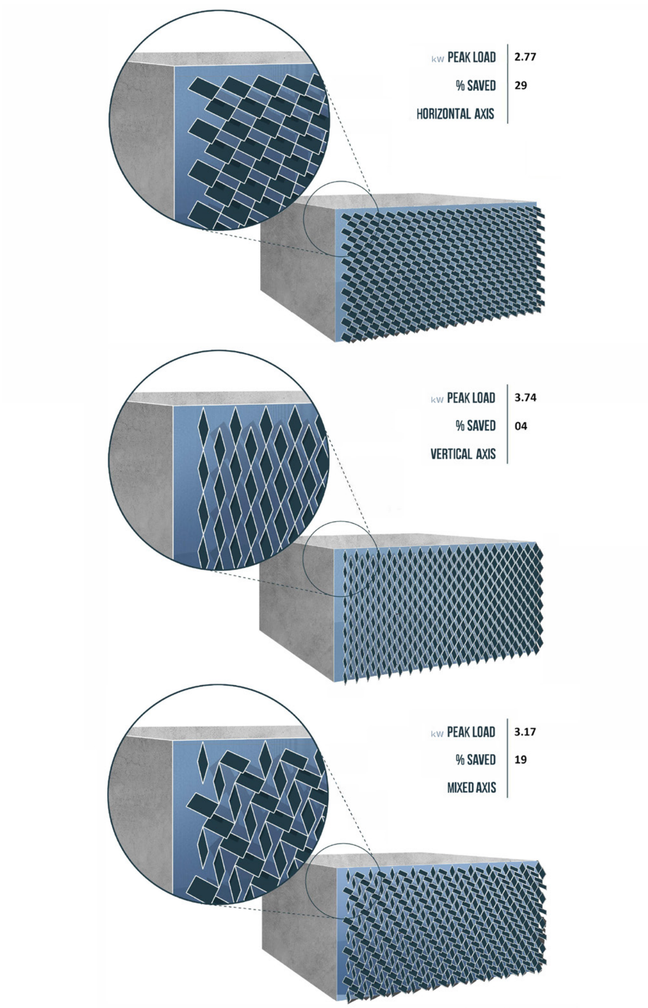

Figure 5. Comparison of the average peak loads. Authors.

RESULTS AND DISCUSSION

The peak load of the baseline was 3.91 kW on average. Compared to this baseline, installing the shading system reduced the peak load by 4 to 29%. Table 1 shows the details of the results, and Figure 4 illustrates the range of the results with a box and whisker plot. Figure 5 compares the average peak loads of horizontal, vertical, and mixed axes scenarios. As shown in the result, horizontal-axis configurations consistently performed best with 30% of the peak load reduction. This finding informs the considerable impact of kinetic shading systems on the energy use of space and highlights the importance of the design of the shading system with a recommendation to focus on the axis for the panels' movements. The significance of this study would be the quantification of the impact of the rotation axis on the performance of kinetic façade systems. This study may inform shading design developments and underscore the importance of shading strategies in building retrofit to enhance energy efficiency, which ultimately promotes sustainable design and reduces grid dependency (Figure 6). Future studies may engage policy issues for sustainable building repair, including incentives like the Net Metering and the Reduction Act.

Figure 6. An example of a typical New Orleans house with the proposed shading systems. Authors.

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ENDNOTES

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