COMPARISION OF FIVE WINDOW SHADE STRATEGIES

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ABSTRACT

Exterior window shades are considered an effective option for passive energy efficient design in hot dry climates such as Los Angeles. Many types are used on the USC campus including block shading plus side fins, overhangs plus side fins, and louvers plus overhangs. These three were modeled and then simulations were run in DesignBuilder. They were evaluated for their comparative effectiveness in reducing annual energy consumption compared with a base case. Because the “louvers plus overhang” performance exceeded the other two strategies, it was disassembled into its two separate components in order to gauge the impact of these individual elements. Each of the strategies was then simulated for all four major orientations in order to evaluate their effectiveness under varying conditions. The results show that energy performance did vary based on shading strategies and their orientations. The results re-emphasize that the type of shading should be dependent on orientation.

1. INTRODUCTION

In the United States, office buildings consume large amounts of electricity every year [1]. During the warmer times of the year, excess solar gains from direct sunlight into a building result in a higher cooling demand. This adds to the need for air conditioning the interior and the building’s electricity load. Providing shading to windows is a common passive method to block excess sunlight. Architects have used different types of shading with different degrees of success in their performance.

Buildings on the USC campus (Los Angeles, California) employ a large variation in shading strategies. There are overhangs, fins, louvers, interior shades, sculpted forms around the windows, tinted glass, inset windows, neighboring buildings and trees (the latter two might not have been designed intentionally as window shades).

For this study, three featured strategies have been selected, then simulated as part of a test cell in DesignBuilder, and evaluated according to their energy performance (Fig.1). Then each of the three shading devices (plus two others) were simulated again for north, south, east, and west orientations in order to observe any impact in the simulated performance (Fig.1). Finally the results have been assembled so as to compare the energy performances of these strategies against each other. A short description of other on-going work is also included.

Fig. 1: Images of three selected shading strategies on the USC campus: block shading + side fins (left), overhang and side fins (middle) and louver plus overhang (right)

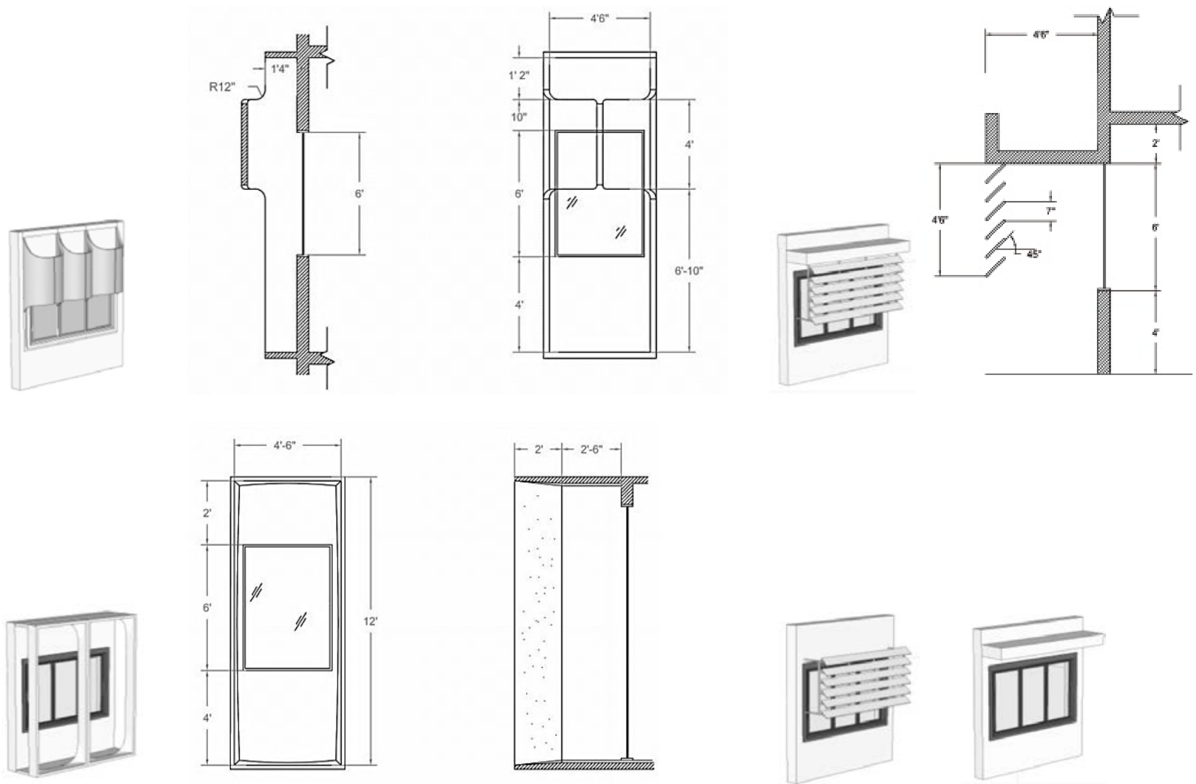


Fig. 2: Geometry and dimensions of the shading strategies tested. A - block shading plus side fins (upper left), b - overhangs plus side fins (bottom left), c - louvers plus overhangs (upper right), d – louvers only, e – overhang only (lower right)

TABLE 1: DESIGNBUILDER SIMULATION SETTINGS

OCCUPANCY	2 PEOPLE 2 COMPUTERS 1 PRINTER
SCHEDULE	WEEKDAYS: 9am-6pm, WEEKEND: OFF
METABOLIC	0.9 (MEN 1 and WOMAN 0.85) [4]
HOLIDAYS	1. HOLIDAY ACCORDING TO CALIFORNIA CODE 2. ADD SUMMER VACATION: MAY.10 - AUG.15 ; ADD WINTER VACATION: DEC.9 - JAN.9
DHW CONSUMPTION RATE	0.005 GAL/SF/DAY
HEATING SET POINT TEMPERATURE	70
COOLING SET POINT TEMPERATURE	75
AIR TIGHTNESS	0.5
GLASS AND WINDOW	DOUBLE GLAZING: 6mm+13mm AIR SHGC: 0.7 , U-VALUE: 0.469 PAINTED WOOD WINDOW FRAME: U-VALE=0.64
LIGHTING	GENERAL LIGTING=1.1 WT/SF, Illuminance :400LUX
ENVELOPE CONSTRUCTION	MEDIUM WEIGHT, MODERATE INSULATION EXTERNAL WALL U-VALUE: 0.062 ROOF U-VALUE: 0.044
HVAC SYSTEM	DUAL DUCT VAV

2. METHOD

2.1 Campus Location and Weather Introduction

California is divided into 16 climate zones, and there are different strategic considerations for effective building passive design in different climate zones [2]. The USC campus is located in zone 8, latitude 33.93 N, and longitude 118.4 W. In this specific climate zone, appropriately designed external shading has the potential to greatly reduce solar heat gains in summer and maximize solar gains in winter, thereby decreasing a building's total annual energy consumption.

2.2 DesignBuilder

DesignBuilder is an EnergyPlus based building simulation software intended to help architects, engineers, and homeowners design more energy efficient buildings [3]. DesignBuilder was selected in this study for several reasons. First, it has the ability to flexibly import shading components from Autodesk Revit Architecture, which offers the possibility of modeling shading devices with complex shapes for further simulation and could greatly ensure the reality of the evaluation. Because this study is focused on the evaluation of existing shading strategies, the perceived reality of the simulation is critical. In addition, DesignBuilder allows for the assignment of shading materials.

2.3 The Building Test Cell

A 14 ft. ×14 ft. ×14 ft. cubic building was created as the test cell (Fig. 3). The settings of the envelope material, HVAC system, etc. are shown in Table 1. In each set of simulations all system settings remained the same. In each simulation, there is only one window oriented towards the direction of interest. The window to wall ratio for this wall is 50%. The other three external walls remain without windows or other openings. North is set to true north (the USC campus is not true north; future work would include more specific studies of the building's true orientation, size, and location.)

2.4 Shading Devices

The three most distinctive existing shading strategies found within the USC campus were selected and measured (Fig. 2, a, b, c). Shading options b (overhang + sidefins) and c (louvre + overhang) were modeled in DesignBuilder based on recorded measurements. Because of its complex shape, the block shading strategy was modeled in Revit and exported into DesignBuilder.

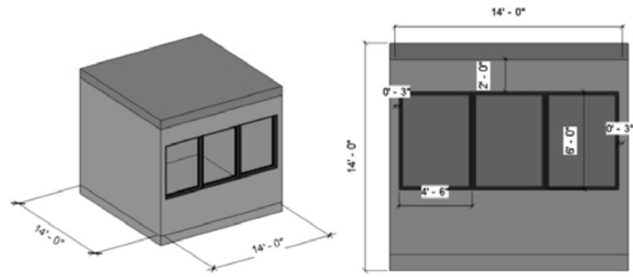


Fig. 3: The geometry and key dimensions of the modeled office module (test cell)

All shading devices were made of opaque material. Their material was set according to observed existing conditions in order to ensure the authenticity of the simulation.

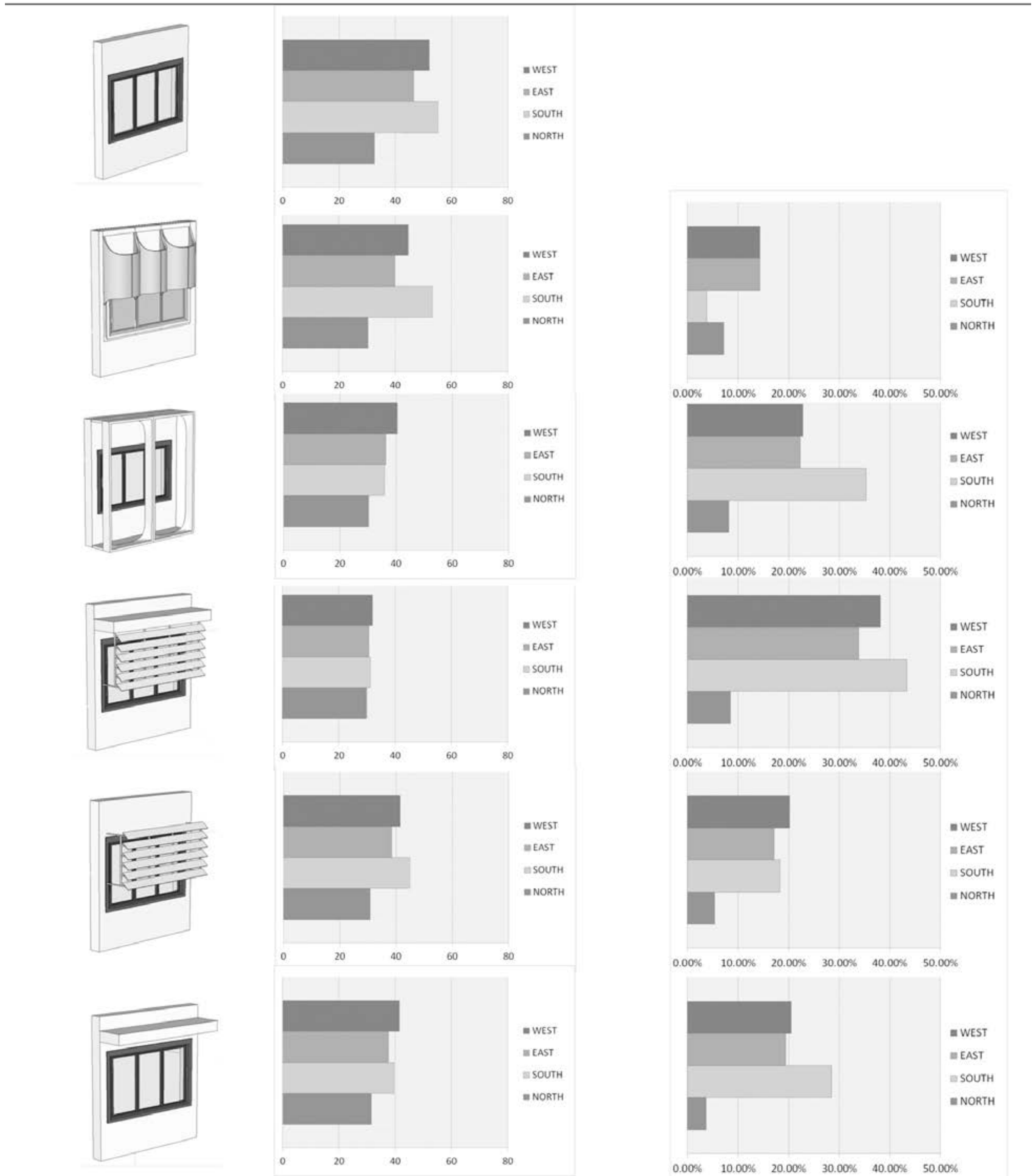
After these three shading strategies were simulated, the results indicated that strategy c's (louvre + overhang) performance exceeded the other two strategies. For the purpose of discussion, this strategy has been disassembled into its two separate components (Fig. 2 e, d). These components were then simulated separately in order to gauge the impact of these individual elements. These simulations were added to the previously established set of three along with the reference simulation (without any shading) for a total of six simulation sets being performed and available for comparison.

3. DISCUSSION

The simulation results are summarized in Table 2. These results demonstrate a reduced impact in all north facing shading strategies, with an energy savings rate of only 2%-8% that was far below the performance of the other orientations. As a result, shading on this orientation will not be included in further discussions.

TABLE 2: SIMULATION RESULTS: ANNUAL ENERGY CONSUMPTION FOR FIVE SHADING STRATEGIES

Annual Energy Per Total Building Area [kBtu/ft²/Year] | **Annual Energy Saving [%]**



3.1 Energy Performance of Reference Test Cell

In order to observe the impact on the energy performance due to the introduction of shading strategies, a baseline must first be established using the previously described reference Test Cell (Fig. 4).

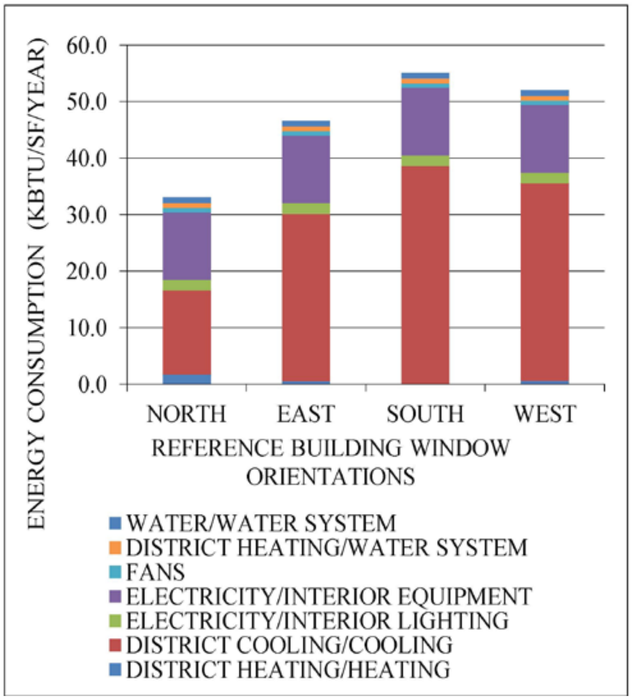


Fig. 4: Energy performance of reference test cell

Energy consumption is made up of seven parts in this study: district heating / heating, district cooling / cooling, electricity / interior lighting, electricity / interior equipment, fans, district heating / water system and water / water system. Cooling and equipment usage are two of the biggest parts. Water usage, water heating, fans and interior equipment load are decided by the room function and will not be influenced by shading. While lighting can be influenced by shading devices in the incorporation of daylight strategies, due to the conditions of the test cell the lighting load for this study is reduced to less than the typically measured 40%-60% of an average office building's total electricity consumption [1]. This is due partially to two reasons:

- The schedule is set to weekdays from 9 am - 6 pm. During this time; the luminance level could usually be achieved by daylight.
- The depth of test cell is 14 feet, which makes it possible to utilize daylighting [5]. This is for the test cell only although it is likely that the configurations of the original buildings that these shading devices were taken from would be conducive to natural lighting.

The cooling energy consumption occupies a very high percentage of the total energy consumption. Heating varies, but as the base number is not sizable, the observed impact is less as well. These test results shows Los Angeles is located in cooling dominated area, where shading could greatly improve building energy performance, which will be shown in "3.4 louvre +overhang" study.

3.2 Block Shading + Side Fins

- Generally, this shading strategy has somewhat less of an impact on a building's energy load. The annual energy saving rate is below 15% on all the orientations.
- South: This shading strategy performs the worse on the south side (5% annual energy saving rate). This is because block shading on the south blocks the low angle sunlight during the winter, thereby reducing solar heat gains which should be maximized in this season, while have difficulty in blocking high degree sunlight in summer. This results in greater solar heat gain in summer and an overall poor performance.
- East and West: Although block shading on the east and west sides block winter sunlight, the summer low angle sunlight was also blocked. As a result the east and west performance exceeds the observed south performance.

3.3 Overhang + Side Fins

- Generally, this shading strategy combination demonstrated a 25%-40% annual energy savings rate.
- The south scheme performs the best as it could reduce solar heat gain in summer while not overly affecting winter solar heat gains.

3.4 Louvre + Overhang

Compared to Fig. 4, Fig. 5 demonstrates a reduced cooling load in summer when the orientation is to the south. Reduced cooling loads are also observed for east and west orientations although at a slightly reduced rate.

- This shading strategy performs very well on all orientations. Annual energy saving rates are listed as follows: east: 35%, west: 38%, south: 45%.
- Although this shading strategy not only blocked sunlight in summer but also in winter, it still had the best energy

performance. This indicates how the cooling load dominates energy consumption in the designated climate.

Properly designed overhang and louvers have the potential to block direct sunshine, introduce diffused light into the building, and aid in working towards achieving sustainable related goals.

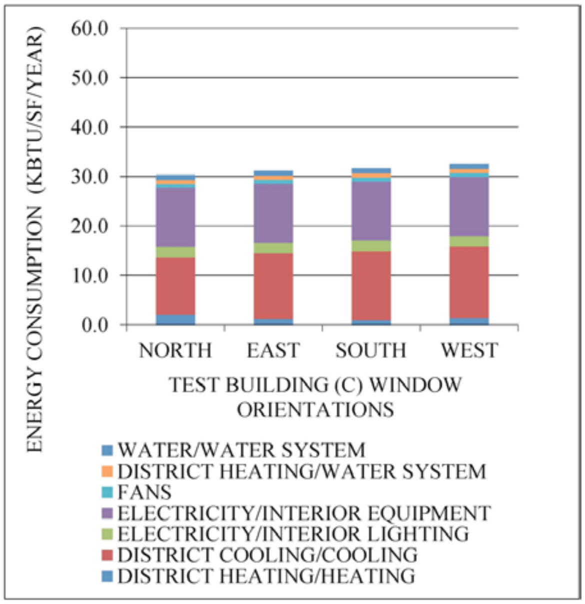


Fig. 5: Energy performance of room with louvre + overhang shading

3.5 <u>Louvre versus Overhang</u>

Louvre shading and overhang shading performed almost equally when oriented towards either the east or the west. For the south orientation the overhang performed slightly better than louver. This is because on south side the overhang allows for more winter solar gains than the louver.

4. CONCLUSION

This study demonstrates that there is an energy consumption impact based on the type of shading strategies employed. In this case study, block shading (Fig. 2a) performed relatively worse than the combination of louver + overhang shading (Fig. 2c), the difference between these two regarding annual energy savings reached as high as 40%. The same shading strategy also performed differently when applied to different orientations. North in particular has a consistently reduced impact on energy efficiency. In addition, the unusual curved block shading elevated the aesthetic performance of the facade, but did not perform well at improving energy efficiency.

As a result it can be stated that improperly selected or located shading devices can reduce the efficiency of a design while correctly combined strategies can increase it. In fact, through the judicious choice of the type and the location of utilized shading devices it appeared possible to save up to 45% of the total annual building energy consumption. Further research is needed to establish whether this level of energy savings holds true when applied to a building rather than a test cell. Window shading is an important strategy to reduce energy loads and thereby reach goals of efficiency and sustainability. However, shading strategies must be carefully evaluated in order to be applied in an effective manner.

5. ON-GOING WORK

Upon completion of this study, we realized that it would have been useful to render shadow masks for each of the window types for each orientation. A correlation between energy saved and amount of window shaded could then be attempted. The connection between the two is more complex when other design concerns such as day lighting are taken into account.

Setting aside exclusively exterior shading systems, a new study focuses instead on light shelf performance. The daylight performance will be evaluated by two metrics, daylight availability and daylight uniformity. This method for optimizing light shelf design uses Diva for Rhino combined with parametric analysis and optimization to develop an integrated solution based on many variables input by the user including room configuration, height, width, curvature, and tilt angle (Fig. 6). Eventually, it should include energy performance as one of its metrics.

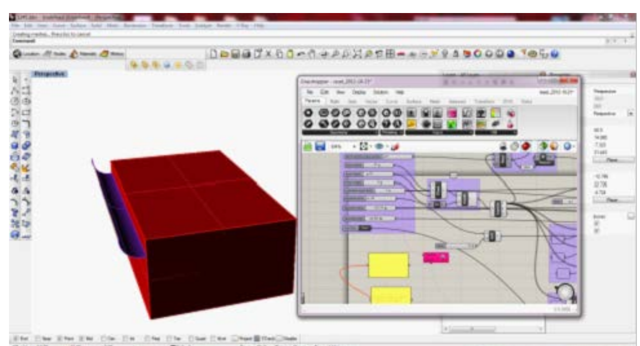


Fig. 6: On-going work: light shelf studies for daylighting

6. ACKNOWLEDGMENTS

The authors would like to acknowledge the many valuable suggestions made by Professor Murry Miline and Tim Kohut.

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