Impacts of Different Window-Shading Assemblies on Energy, Thermal Comfort and Daylighting for a South Facing Mid-Rise Office Building in Florida

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ABSTRACT

With an ever increasing cooling energy demand of buildings in hot and humid climates like in Florida, using a well designed window-shading system is considered as an efficient strategy that minimizes the direct sunlight reaching indoors and thus reduces the overall energy loads. While reduction in energy loads is important, the indoor comfort of occupants should not be compromised. Individual thermal and solar properties of glazing and shading systems only provide information based on static evaluations but it is very important to assess the efficiency of these systems as a whole assembly under the site specific conditions. This research was conducted to evaluate the impacts of using different types of window-shading assemblies on the overall performance of a south-facing office building in Florida through 1) calculating total energy consumption; and 2) analyzing indoor thermal and visual comfort. The results were then presented to suggest economic and efficient design strategies for south oriented facades.

INTRODUCTION

Florida has become the nation's fourth largest energy consuming state in commercial sector utilizing about a thousand trillion BTU's and having a gross expenditure of over ten billion dollars per year (EIA 2010). In an effort to decrease the carbon footprint of this high commercial energy consumption, more stringent rules have been defined for envelope design in Florida Building Code Energy Conservation (FBC 2010). Each face of a building requires a different shading treatment because the sun's angle of incidence is different on each face (Griffith et al. 2007; Huang et al. 2007; Raheem 2013). The past research has shown that the overall effectiveness of the sun-shading device depends on its performance for all sun positions (Karlsson et al. 2000; Huang et al. 2007). The proper use of shading devices may reduce the cooling loads by15-20% (depending on the amount and location of the windows) (Dubois 1997; Bourg 2008; Ali et al. 2012). South façades are critical to design properly as during the day a large amount of energy from the sun is received through glazing and usually most of the sunlight gets concentrated in certain areas of the space if the facade is not properly designed (Littlefair 1995; LBNL 2004). This may result in glare on work surfaces causing discomfort for the occupants (Galasiu et al. 2006; Wienold 2006).

Individual thermal and optical properties of glazing and shading systems only provide information based on static evaluations but it is very important to assess the efficiency of these systems as a whole assembly under the site specific conditions. The main objective of this study was to investigate the impacts of these thermal and optical properties on the overall performance (energy consumption, and thermal and visual comfort) of south facing mid-rise office building in a hot and humid climate.

RESEARCH METHODOLOGY

The research was conducted in three phases: 1) modeling and simulation, 2) analysis and 3) comparison. Software COMFEN 5 was used for modeling and simulation. This is an analysis tool based on EnergyPlus software and is used to evaluate the façade performance of commercial buildings considering different design scenarios. The base model used in this research was a three storey office building with an area of 4000ft^2/floor located in Miami, Florida. The base model was simulated using nine different types of shading devices under three broad categories: exterior shading devices, between glass shading devices and interior shading devices (Table 1). The building model was simulated mutliple times for 36 different window-shading assemblies. The results were analyzed in terms of total annual energy consumption and heat gains through glazing. The results obtained through analysis were then compared to find an optimum window-shading assembly for the south façade with the least energy consumption and maximum indoor thermal and visual comfort.

Table 1. Properties of Shading and Curtain Wall Frame

No.	Location	Shading Type
1	Exterior	Venetian blind 3” slat (slat angle 45°) Slat conductivity= 92.03 Btu/ h-ft-F Width-spacing-thickness= 3.03”-2.76”-0.04”
2		Venetian blind 3” slat (slat angle 90°) Slat conductivity= 92.03 Btu/ h-ft-F Width-spacing-thickness= 3.03”-2.76”-0.04”
3		Roller shade Solar transmission =0.15; Solar reflectance=0.3 Thermal emissivity= 0.9; Conductivity= 0.17 Btu/h-ft-F Thickness= 0.03”; shade-to-glass distance= 3”
4		Screen w/fine mesh (1mm) Solar reflectance= 0.1; Conductivity= 0.17 Btu/h-ft-F
5		Horizontal wall overhangs
6	Between glass	Venetian blind 0.45” slat (slat angle 45°) Slat conductivity= 92.03 Btu/ h-ft-F Width-spacing-thickness= 0.45”-0.3”-0.04”
7		Roller shade

		Solar transmission =0.15; Solar reflectance=0.3 Thermal Emissivity = 0.9; Conductivity= 0.17 Btu/h-ft-F Thickness= 0.03”; shade-to-glass distance= 1”
8	Interior	Venetian blind 1” slat (slat angle 45°) Slat conductivity= 92.03 Btu/ h-ft-F Width-spacing-thickness= 1”-0.79”-0.04”
9		Roller shade Solar transmission =0.15; Solar reflectance=0.3 Thermal Emissivity = 0.9; Conductivity= 0.17 Btu/h-ft-F Thickness= 0.03”; shade-to-glass distance= 1”

INPUT DATA FOR MODELING AND SIMULTION

Simulation software: COMFEN 5.0.5
Building Type: Office building
Geographical location: Miami FL; 25 49′ 26″ N 80 17′ 59″ W
IECC climate zone= 1
Heating and cooling degree days (U.S. census Bureau 2009): HDD=149; CDD=4361
Building dimensions (LxWxH) = 80’ x 50’ x 30’
Weather data file used= TMY3
Required EnergyPlus file types= *.epw, *.stat, and *.ddy

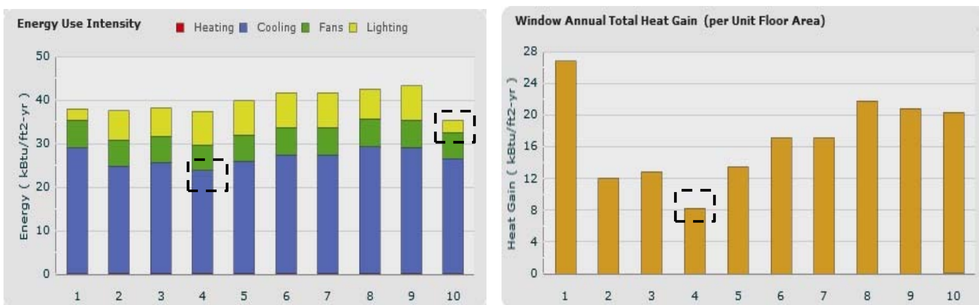
Building components and space properties. The ASHRAE standard 90.1 was used to determine envelope insulation requirements for the Miami climate. The lighting and cooling load values were used as suggested in the ASHRAE guide for energy efficient small office buildings (ASHRAE 2004). The outdoor air flow rates used for ventilation were based on the area of the building (flow/area: cfm/ft^2) (ASHRAE 90.1). Average carbon emissions per unit of electricity (generated by utility and nonutility electric generators) and gas values were taken from data provided by the EIA (EIA 2002). The utility rates selected were an average price of electricity and used by end-user in the commercial sector (EIA, 2011b; EIA 2011a). Aluminum frames with thermal break were used and the thermal properties of the selected frame were representative of currently available commercial curtain wall systems. The selected glazing systems had U-values ranging between 0.1 and 0.3 and SHGC below 0.5 with double and triple glass types (Table 2). These systems were comprised of multiple glass-gas layers and their thermal and optical properties like U-values, T_{vis} (visible transmission) and SHGC (Solar Heat Gain Coefficient) were calculated using WINDOW 7 software.

Table 2. Selected Glazing Systems for Simulation

Glazing type	U-value (Btu/h-ft^2-F)	SHGC	T_{vis}	Thickness (in)
Double glass low solar low-E clear (Argon)	0.23	0.37	0.7	0.95
Double glass low T_{vis} low-E (Argon)	0.203	0.241	0.371	0.95
Triple w/suspended film; dual low-E	0.144	0.467	0.631	1.45
Triple, dual low-e; pyrolytic	0.145	0.3	0.541	1.67

ANALYSIS

The analysis was performed for four sets of window-shading assemblies while each set is comprised of one glazing system with all nine selected shadings. The energy consumption was measured for heating, cooling, fans and lighting. For the first set of window-shading assemblies, double glass (low solar low-E clear (Argon)) with nine different types of shading was simulated keeping all the other design and space parameters same in each simulation. It was observed that the least amount of total energy (for heating, cooling, fans and lighting) was consumed when overhangs(10) were used whereas exterior roller shades(4) were the most efficient ones in reducing cooling loads (Figure 1(a)) due to the least heat gains through windows (Figure 1(b)).

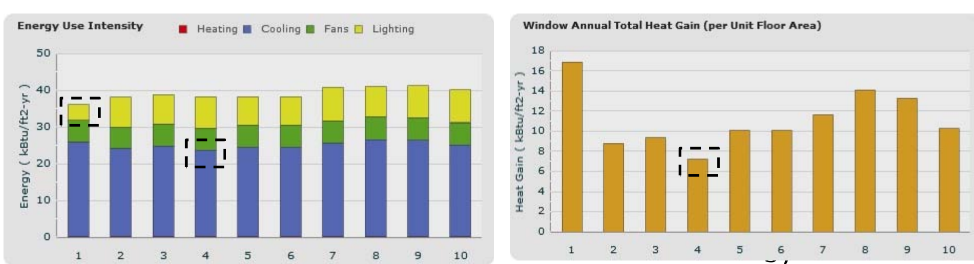
a)


(b)

Figure 1. Analysis of the first set of window-shading assemblies a) Energy consumption b) Annual heat gains through glazing

Horizontal axis: 1-no sunshade; 2-External venetian blind 45°; 3-External venetian blind 90°; 4-External roller shade; 5-External screen; 6-Between glass venetian blind; 7-Between glass roller shade; 8-Internal venetian blind; 9-Internal roller shade; 10- Overhangs

For the second set double glass (low T_{vis} low-E clear (Argon)) with nine different types of shadings was simulated again keeping all the other design and space parameters the same in each simulation. The results in this case showed a decrease in the total energy consumption and window heat gains for each of the window-shading assemblies. It was further observed that the least amount of total energy (for heating, cooling and electricity) was consumed when no shading device was used. The cooling loads were not lowest in this case but lighting loads were reduced due to higher availability of the daylight, causing the lowest total energy consumption. Exterior roller shades were the most efficient in reducing cooling loads due to the least amount of heat gains through windows in this set as well (Figure 2).

a)


b)

Figure 2. Analysis of second set of window-shading assemblies a) Energy consumption b) Annual heat gains through glazing

Similarly third and fourth set of window-shading assemblies were analyzed and the optimum options were selected for comparison.

COMPARISON

Three best performing window-shading assemblies were selected from the four sets after analyzing their energy performance for the south facing glazed wall (Figure 3). These assemblies were:

- Double glass low VT low-e (Argon) with no shading device (A1)
- Double glass low solar low-e (Argon) with overhangs (A2)
- Triple glass, dual low-e; pyrolytic (A3)

These selected assemblies were further compared for energy performance and indoor comfort on a monthly and annual basis.

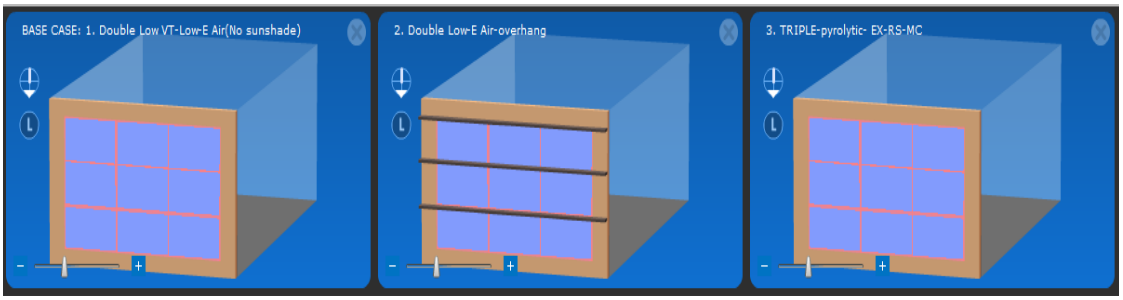
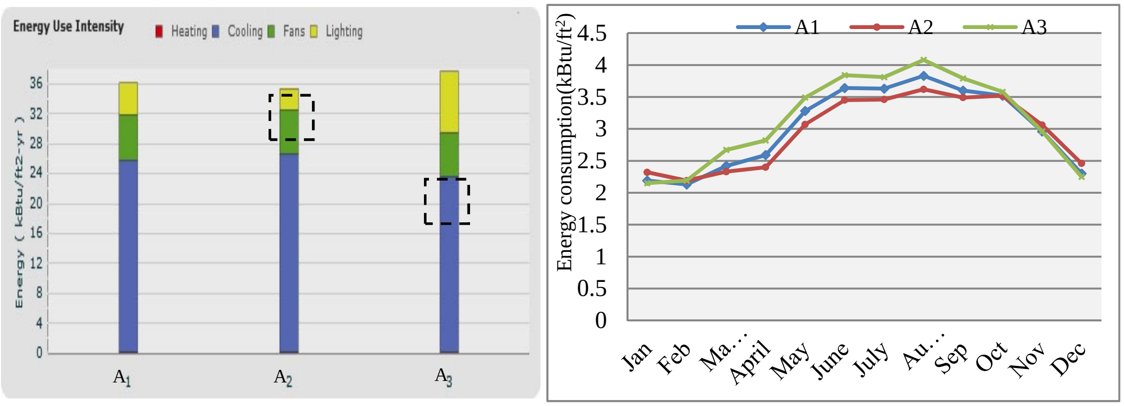


Figure 3. Window-shading assemblies selected for comparison

Annual energy consumption..The total energy usage was calculated as the sum of energy used for heating, cooling and fans and lighting). Based on the total energy use values, double glass low solar low-e with overhangs (A2) was the most efficient assembly in the current scenario. From the monthly energy consumption profile, it was observed that from March through September assembly A2 performed better than other two (A1, A3) but from Jan-Feb and Oct-Dec all the three assemblies were performing nearly in the same manner (Figure 4) because the direction of conductive heat flow is from inside to outside of building during these months in Miami.



a) **b)**

Figure 4. Energy consumption a) Annual profile b) Monthly profile

Indoor comfort

Thermal comfort. Three selected assemblies were analyzed in terms of thermal comfort and results were obtained as a percentage of people satisfied which is a direct output of the software used (Table 3). The A3 assembly was the most efficient one having the highest percentage of people satisfaction and least number of hours in a year when hourly temperature set points were not met.

Table 3. Thermal Comfort Analysis

	A1	A2	A3	A3 vs. A1	A3 vs. A2
Average thermal comfort (PPS)	86.37	85.09	88	>2%	>3.3%
Hourly temperature set points unmet (hours)	1173	1223	875	-289	-348

Daylighting and glare analysis. A daylight analysis was performed for the selected assemblies and daylight illuminance maps were generated for a summer day (June 21st at 11:00AM). These maps were generated by the EnergyPlus engine working behind COMFEN software. These maps displayed work surface illuminances, calculated at 2'-6" (0.762 m) above the floor (default value), for the entire space in the form of a 10 x 10 grid (the grid is scaled to fit the space in the software). The maps showed high illuminance values for assemblies A1 and A2 near the façade area inside the office whereas low but uniform illuminance level was observed when using assembly A3 because the roller shades were on at that time of the day (Figure 5).

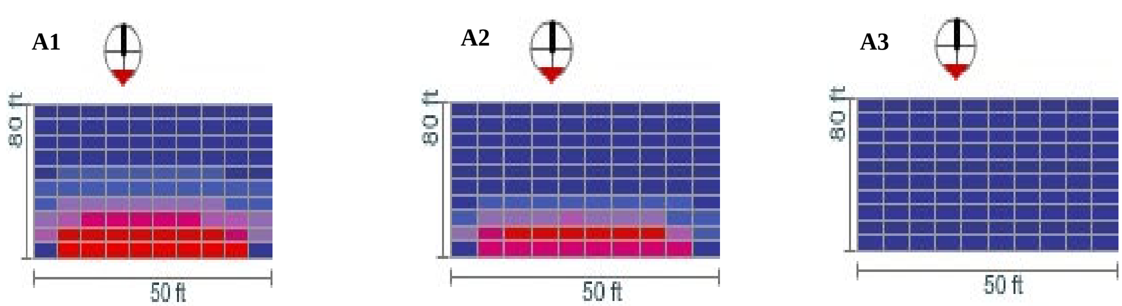


Figure 5. Daylight analysis- Daylight illuminance maps

The annual daylighting profile was created with a sensor positioned at two-thirds of the primary daylight zone depth from the facade wall and positioned at desk height of 2’-6" (0.76 m) above the floor (standard option in the software). The profile showed the highest illuminance values (monthly average) when assembly A2 was used (Figure 6).

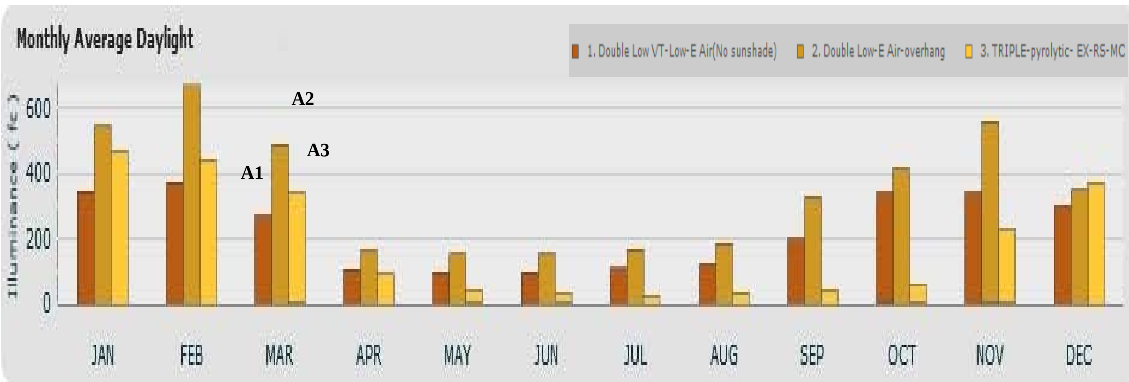


Figure 6. Monthly illuminance profile

CONCLUSIONS

Although energy consumption is an important factor in evaluating building performance, the ultimate goal is to ensure the indoor comfort of the building occupants. This study looked at the effects of different window-shading assemblies for a south facing glazed wall in the hot and humid climate of Miami, Florida. It was observed from the analysis that shading devices behave differently (in terms of overall efficiency) with different glazing systems. For south facades exterior shading such as roller shades and overhangs are the most efficient options when combined with glazing systems having low U-value and SHGC (<0.3). The analysis also showed that although the least amount of energy was consumed annually when overhangs were used but they are not the best option in terms of providing indoor comfort for the occupants. Having a physical model for validation is an expensive option but sensor technology can be used in existing south facing buildings with proposed window-shading assemblies.

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