Environmental Performance Evaluation of Different Glazing-Sunshade Systems Using Simulation Tools

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***Abstract*— With the increasing capabilities of computer modeling and simulation technology, the analysis of options for maximizing gains in energy efficiency for buildings can be realized more efficiently and cost effectively. Conducting building performance simulations allows for the analysis of the environmental impacts of buildings at the early design stages. Commercial buildings consume nearly one fifth (18 quads) of all the energy used in the United States, costing more than $200 billion each year. The building envelope plays a key role in determining how much energy is required for the operation of a building. 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 site-specific conditions. This paper presents a case study that was conducted using computer simulation tools to evaluate the environmental impacts of using different types of glazing-sunshade systems on the overall performance of an office building. The case study results show how early stage building performance studies using computer simulation tools help practitioners in achieving the goals of reduced energy consumption and increased indoor comfort in an economical manner.**

Keywords- Simulation; Energy consumption; Indoor comfort; Commercial buildings.

I. INTRODUCTION

The use of computer modeling and simulation tools during the early design phase can be very helpful to obtain more reliable building performance predictions [8][19]. The models can be a simple building information model (Level Of Development (LOD) 200) or detailed one (LOD 300) depending on the owner's requirements or other physical conditions [3]. A major advantage of using these tools is the comparison of the environmental performance of different design alternatives to improve the overall building design efficiency [13].

According to the U.S. Department of Energy [21], commercial buildings consumed about 18.26 quads of primary energy in 2010, which represents 46% of building energy consumption, 19% of U.S. energy consumption and 18% of U.S. carbon dioxide emissions. Space heating, lighting and cooling were the major end uses representing 26.6%, 13.6% and 10.1% respectively of the total energy consumed by the commercial buildings during the same year [21]. The energy performance of building envelope components is critical in determining how much energy is required for heating, cooling and lighting. Energy efficiency measures such as properly designed envelopes in commercial buildings provide an opportunity to reduce energy consumption and costs, and to reduce greenhouse gas (GHG) emissions at the same time.

Florida has become the nation's fourth largest energy consuming state in the commercial building sector utilizing about a Quadrillion BTU's in commercial consumption and having a gross expenditure of over $10 billion per year in this sector [24]. Of the total energy that Florida produces per year, more than 90% comes from non–renewable sources like coal and gas contributing 4.8 million metric tons of energy related carbon-dioxide emissions from the commercial building sector to the total emissions per year. In an effort to decrease the carbon footprint of this high energy consumption in commercial buildings, more stringent rules for building envelope design have been adopted in the Florida Building Code's Energy Conservation Code section [11]. Much of the emphasis is given to the window to wall ratio, U-factor and solar heat gain coefficient (SHGC) of window glass and frame type while describing the energy efficient window strategies in Section 502 (Building envelope requirements) of FBC 2010. Although there is a potential for the use of advanced window systems such as switchable electrochromic or gasochromic windows in reducing the overall energy loads, widespread use is unlikely to occur in the near future due to high initial costs and lack of technical expertise [16][14]. Hence other related options such as automated shading systems could be deployed while satisfying the thermal and daylighting requirements of the occupants.

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II. LITERATURE REVIEW

Wherever Individual thermal and optical properties of glazing/shading systems only provide information based on static evaluations. However, it is very important to assess the efficiency of these systems as a whole assembly under site-specific conditions. Cazes [6] found that a positive energy balance (which depends on the season, building type and operation of the building) can be achieved using advanced static glazing combined with well-insulated window systems and architectural shading optimized for seasonal impacts. Past research has shown that the proper use of shading devices may reduce the cooling loads by 15-20% (depending on the amount and location of the windows) [4] [5] [9]. The occupants in commercial buildings often complain about too much solar heat and glare, both of which can be reduced by the use of advanced glazing systems that are tuned to reject as much heat as possible while transmitting high levels of visible light and preventing glare. Combining these advanced solar control glazing (static SHGC) and exterior architectural shading offers an improved solution [14]. Although there is a great potential for advanced window systems such as switchable electrochromic or gasochromic windows in reducing the overall energy loads, still more research and economies of scale are needed so that these systems can become cost-effective (market viable) for mainstream markets (Table I) [14].

There are several variables that influence the thermal comfort of building occupants such as personal variables, environmental variables and physiological variables [1] [10] [15]. The personal and physiological variables are controlled/owned by the occupants. The effects of external environmental variables on the indoor comfort of the occupants can be controlled through a proper fenestration design. It is critical to design south façades properly since during the day they receive a large amount of energy from the sun through the glazing and usually most of the sunlight gets concentrated in certain areas of the space if the facade is not properly designed [17][18]. This may result in glare on work surfaces causing discomfort for the occupants [12] [25].

TABLE I. BEST AVAILABLE TECHNOLOGIES (BAT) FOR WINDOWS AND CLASSIFICATION BASED ON MARKET READINESS (ADAPTED FROM [13])

Key Technical Attribute	**BAT (Market Viable)**	**BAT(Pre-market Viable)**	**Future Technology**
Low U-value	Triple-glazed, dual low-e-coating, advanced frames	Quadruple-glazed, exotic inert gases, aerogel-filled frames	Vacuum-insulated glass, market- viable, multiple-glazed cavity system
Variable SHGC	Automated shade control, exterior shading, architectural features	Dynamic solar control	Dynamic glazing

III. METHODOLOGY

The research was conducted in three phases: 1) modeling and simulation, 2) analysis of total annual energy consumption and heat gains through glazing and 3) comparison of results for the three best performing glazing-sunshade systems.

A. *Modeling and Simulation*

The COMFEN 5 [7] software was used for energy and visual modeling and simulation. This is a single-zone façade analysis tool based on EnergyPlus software and it is used to evaluate energy, thermal and visual performance of commercial building façades using different design scenarios. COMFEN provides comparative perimeter zone performance results between façade design options.

The base model used in this research was an office building (80’ x 50’) with an area of 4000ft^2 located in Miami, Florida. The model was designed for the south façade consisting of a curtain wall system (glazing/façade ratio=0.67). The curtain wall was simulated for 40 different glazing-sunshade systems (four glass types, nine shading systems and a base case of glazing with no sunshade). The base model was simulated using nine different types of shading systems for three possible locations relative to the window (exterior, between glass and interior)(see Table II).

B. *Analysis of total annual energy consumption and heat gains*

The building model was simulated multiple times for different glazing-sunshade systems. The results were analyzed in terms of total annual energy consumption and heat gains through glazing. The three best performing glazing-sunshade systems were then selected to compare their overall performance in terms of energy and indoor comfort.

C. *Comparison of the three best performing glazing-sunshade systems*

The results obtained through analysis were then compared to find an optimum glazing-sunshade system for the south façade with the least energy consumption, maximum indoor thermal and visual comfort

TABLE II. CATEGORIES OF SHADING DEVICES USED IN THE BASE MODEL

Categories of shading devices	**Types**				
	Venetian blinds (45°)	Venetian blinds (90°)	Screen	Rolling shades	Overhangs
Exterior	×	×	×	×	×
Between glass	×			×	
Interior	×			×	

The comparison was made under two categories:

- Energy consumption: Annual energy and peak demand impacts
- Indoor comfort analysis: Thermal comfort, daylighting and glare

IV. INPUT DATA FOR MODELING AND SIMULATION

The following input was used for modeling and simulation:

- Geographical location: Miami FL; 25 49′ 26″ N 80 17′ 59″ W
- IECC climate zone= 1
- Heating and cooling degree days [10]: HDD=149; CDD=4361
- Building dimensions (LxW)= 80’ x 50’
- Weather data file used= TMY3
- Required EnergyPlus file types= *.epw, *.stat, and *.ddy

The climate of Miami is essentially subtropical, characterized by a long and warm summer, with abundant rainfall, followed by a mild, dry winter. The annual temperature profile shows high temperatures during summer (above 90°F) with similar peaks of direct and diffused solar radiations. Due to high outside temperature, Miami requires both sensible and latent cooling most of the year.

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[2]. The outdoor air flow rates used for ventilation were based on the area of the building (flow/area: cfm/ft2) (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 [23]. 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 III). 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 III. SELECTED GLAZING SYSTEMS FOR SIMULATION

ID	Glazing type	U-value (Btu/h-ft^2-F)	SHGC	T_{vis}	Thickness (in)
G1	Double glass low solar low-E clear (Argon)	0.23	0.37	0.7	0.95
G2	Double glass low T_{vis} low-E (Argon)	0.203	0.241	0.371	0.95
G3	Triple w/suspended film; dual low-E	0.144	0.467	0.631	1.45
G4	Triple, dual low-e; pyrolytic	0.145	0.3	0.541	1.67

V. ENERGY CONSUMPTION AND HEAT GAIN ANALYSIS

The energy consumption and heat gain analysis was performed for four sets of glazing-sunshade systems with each set comprised of one glazing system with all ten selected shadings. The energy consumption was measured for four energy usage categories: heating, cooling, fans and lighting. For the first set of glazing-sunshade systems, double glass (G1- low solar low-E clear (Argon)) with different types of shading (S1-S10) was simulated keeping all the other design and space parameters the 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 (Fig. 1(a)) due to the least heat gains through windows (Fig. 1 (b)).

For the second set double glass (G2 - low T_{vis} low-E clear (Argon)) with different types of shadings (S1-S10) 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 glazing-sunshade systems. It was further observed that the least amount of total energy (for heating, cooling and electricity) was consumed when no sunshade system was used. Similarly, the third and fourth sets of glazing-sunshade systems were analyzed and the best options were selected for the final comparison in terms of energy and indoor comfort.

VI. COMPARISON OF ENERGY PERFORMANCE AND INDOOR COMFORT

Three best performing glazing-sunshade systems were selected from the four sets after analyzing their energy performance for the south facing curtain wall. These systems were:

- A1: Double glass low VT low-e (Argon) (G2) with no sunshade system (S1)
- A2: Double glass low solar low-e (Argon) (G1) with overhangs (S10)
- A3: Triple glass, dual low-e; pyrolytic (G4) with external roller shades (S4).

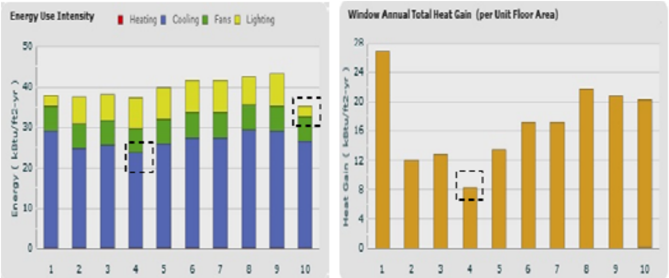

Figure 1. Analysis of the first set of glazing-sunshade (G1 and S1-S10):
(a) Energy consumption (b) Annual heat gains through glazing.
Horizontal axis: 1-no sunshade; 2-External venetian blind 45°; 3-External venetian blind 90°; 4-External roller shade; 5-External screen; 6-Between glass venetian blind; 7-Between glass roller shade; 8-Internal venetian blind; 9-Internal roller shade; 10- Overhangs

These selected systems were further compared for 1) energy performance and 2) indoor comfort

A. *Energy Consumption*

The total energy usage was calculated as the sum of the three energy use types (heating, cooling and electricity (fans and lighting). Based on the total annual 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 the other two (A1, A3) but from Jan-Feb and Oct-Dec all three systems were performing nearly in the same manner (Fig. 2) because the direction of conductive heat flow is from the inside to the outside of the building during these months in Miami.

B. *Indoor Comfort*

Thermal comfort. Three selected systems 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 IV).

The A3 assembly provided the best thermal comfort as it had the highest percentage of people satisfied, and least number of hours in a year when hourly temperature set points were not met (Fig. 3).

Daylighting and glare analysis. A daylighting analysis was performed for the selected systems and daylight illuminance maps were generated for a summer day (June 21st at 11:00AM). These maps display 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 within the software). The maps showed high illuminance values for systems A1 and A2 near the façade area inside the office, whereas a low, but uniform illuminance level was observed when using assembly A3 because the roller shades were automatically positioned (e.g. closed either fully or partially) at that time of the day (Fig. 4)

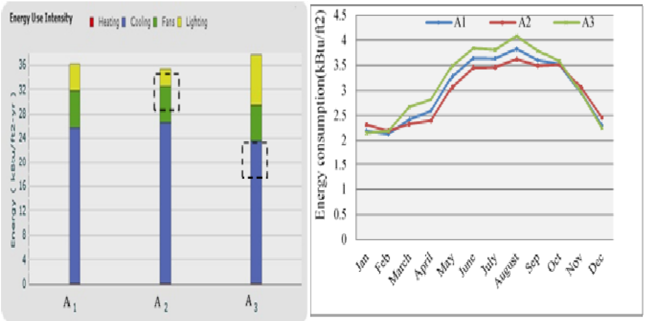

Figure 2. Energy consumption: (a) Annual profile, (b) Monthly profile

The selected systems were further compared to study the glare during a clear summer day from the South side. The occupant's position (X=9.3, Y=15.6) and angle of view (X=6, Y=-9.6) were defined and point-in-time simulations were run for June 21st at 9:00AM, 12:00PM and 3:00PM (Fig. 5). It was observed that use of systems A1 and A2 caused very high values of glare (>185cd/ft2 (2000cd/m2)) during the morning and afternoon which is uncomfortable for the occupants whereas use of assembly A3 caused low glare values (average was less than 69cd/ft2 (750cd/m2)) (≈55% less than A1 and 61% less than A2 at noon) during most the daytime.

VII. CONCLUSIONS

This case study was conducted using energy simulation software to look at the environmental of different glazing-sunshade systems for a glazed office building in the hot and humid climate of Miami, Florida. It was observed from the analysis that sunshade system 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, they are not the best option in terms of providing indoor comfort for the occupants.

TABLE IV. THERMAL COMFORT ANALYSIS

Thermal Comfort Factors	**Window Shading Assemblies**				
	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

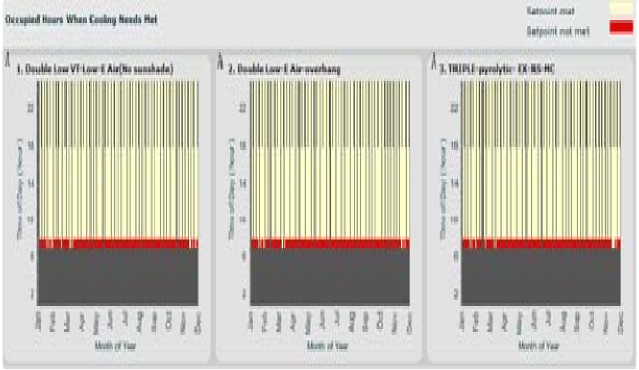

Figure 3. Occupied hours in the building when cooling needs are met.

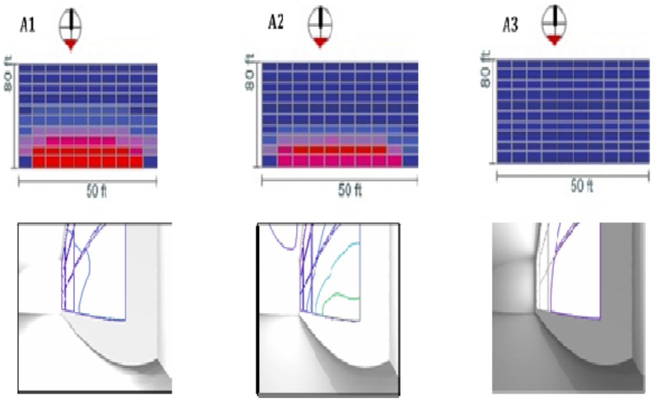

Figure 4. Daylight analysis- Top: Daylight illuminance maps; Bottom: Perspective view illuminance contour lines.

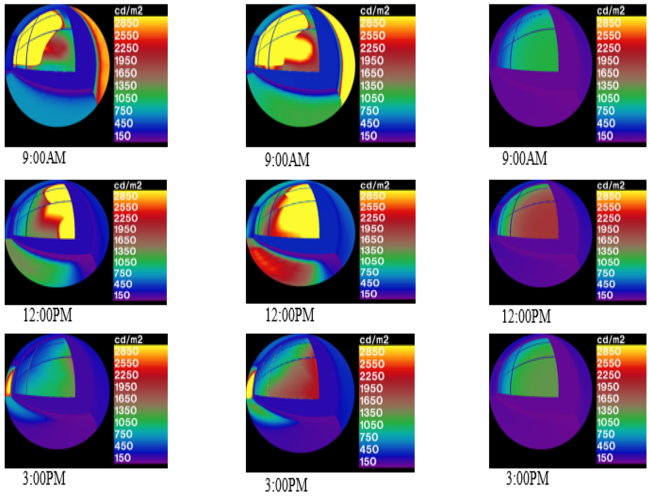

Figure 5. Rendered images from Radiance showing luminance ranges for the selected systems (A1, A2, and A3) during different times of a summer day (June 21st).

More specifically the following conclusions were reached for the south façade glazing-sunshade system design:

- Glazing-sunshade systems with very low thermal and visual properties (visual transmittance (<0.3), U-value (<0.25) and SHGC (<0.25)) like system A1 used in this study can provide some degree of sun control without any sunshade system but can also increase glare and thus do not provide a comfortable indoor environment for the occupants. These systems can help in decreasing electrical loads but compromise the indoor comfort.
- Glazing-sunshade systems with relatively high visual transmittance (<0.8), low U-value (<0.25) and moderate SHGC (<0.4) (like system A2 used in this study) can work efficiently with fixed horizontal shading such as overhangs. Because of the low initial cost, this may be the preferred system; however, indoor comfort is compromised due to high glare during the morning and afternoon hours.
- Glazing-sunshade systems with a moderate visual transmittance (<0.6), low U-value (<0.2) and low SHGC (<0.3)) (like system A3 used in this study) worked efficiently with external shades, such as roller shades and venetian blinds, to reduce cooling loads and permit filtered views. Because of less conduction of direct sunlight (automated control), glare is reduced at times when the horizontal solar angle is low.

The conclusion of this case study is that for the occupant's comfort relative to the standard thermal and visual set points, multiple-pane glazing systems with external sunshade systems such as architectural components (overhangs) and roller shades are an efficient strategy for south facing facades installed on office buildings in Miami. Furthermore, the results indicate early building performance studies using computer simulation tools are helpful to practitioners in achieving the goals of reduced energy consumption and increased indoor comfort.

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