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SENSITIVITY ANALYSIS APPLIED ON BUILDING SIMULATION IN EARLY DESIGN STAGES

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ABSTRACT

The complexity of the building simulation task, including time consumed for modeling, testing, quality assurance and reporting is a difficulty to insert this practice in the early design stages of buildings. In this paper, building simulation was conducted to support design team to define strategies for energy efficient façade in an office Building in São Paulo, Brazil. The project was designed for LEED® certification in Core and Shell category. A sensitivity analysis was carried out through EnergyPlus simulation to help the architect to define the parameters: window-to-wall ratio; type of glass; the use of spandrel glass and wall construction. A simplified building model was developed to conduct the simulation in the early design stage. A total of 132 cases were simulated and the results were selected according to the energy savings achieved against the baseline building, according to ASHRAE Standard 90.1 approach. The use of fully glazed façade has become common in Brazil. Such strategy has been always criticized, as in tropical climate, the solar heat gain through windows is very significant to cooling loads. The sentivity analysis resulted in building models with energy savings varying from 5% to 11%. This work confirms that the façades of this type of building, with solar selective glazing system, high performance HVAC and lighting systems, have less impact on annual energy consumption than conventional building, with clear glass and low efficiency systems.

Keywords: Energyplus, office buildings, tropical weather.

1. INTRODUCTION

The building simulation is usually performed in the final stages of the design, without necessarily following its development stages, using specific and already defined input data. Regardless of whether it is in the initial or final phase, applied to a new project or retrofit, the objective is to justify quantitatively the decisions used (Bazjanac et al, 2011).

Teams usually develop their projects until they have enough definitions for the simulation to take place, without having the perception of how much preliminary evaluations can aid in decision making and provide important guidelines for the development sequence of the projects. Therefore, according to Hemsath (2013), energy modeling acts secondary in the architect's mind during the design phase.

Sensitivity analysis helps clarify which strategies are appropriate for each project and its implementation, so that the performance aspects also serve as one of the project definition factors (Glassman, 2015; Itard, 2005; Jones et al, 2013). Parametric simulations allow the evaluation of multiple potential project variations and, through specific guidelines, can guide design teams serving as a valid starting point during the design development phase (Samuelson et al, 2016; Degens, A., Scholzen, F., Odenbreit, C., 2015). Brígitte and Ruschel (2013) argue that when it comes to technical performance, testing the proposed solutions through computational simulation as a preliminary assessment of the performance decreases process time and assists in decisions, even in the early stages of design.

2. OBJECTIVE

This paper explores the use of parametric and sensitivity analysis in the early design phase of an office building, located in São Paulo, Brazil.

3. METHOD

An office building designed for LEED® certification process was the object of study. Sensitivity analysis was carried out in the early design stages. The project comprises two building towers. Typical floors were modeled in the EnergyPlus software.

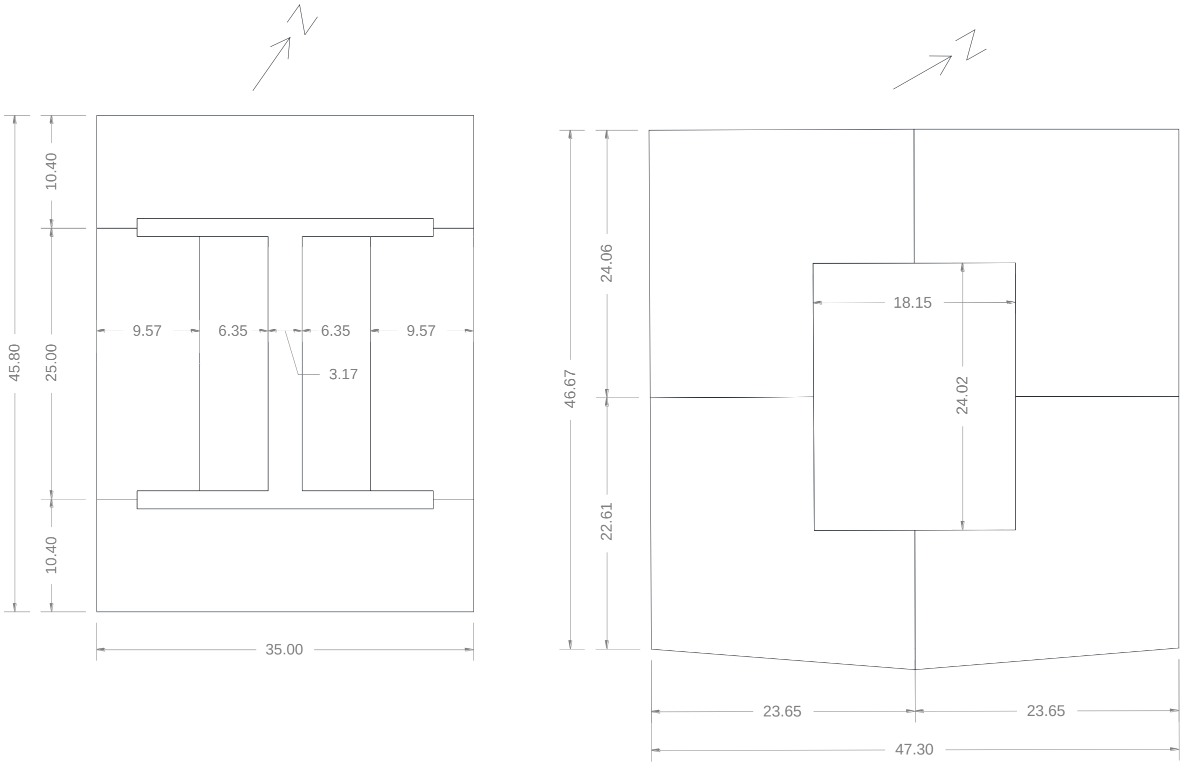
At this phase of the design, the common issue is to define how to model the building if the building is not designed yet. Usually, the shape of an office building to be constructed in an urban environment is defined by the landscape format. The main goal of the architectural design is to achieve the highest constructed area as possible. Then the fine tuning in the design step is applied to adjust the interior layout, with stringent restriction in most of case, as unobstructed visual contact in all façades, and the façade design itself.

LEED® projects in Brazil are conceived with a high efficiency HVAC and lighting systems. With low energy use from these systems, the design of the façade can lead to little influence on annual energy cost of the building.

The main characteristics of the building under analysis is presented in Table 1 and the building model is presented in Figure 1.

Table 1 – Main characteristics of the building.

City	**São Paulo, Brazil**
Total constructed area	139,000 m²
Number of floors	Tower I with 18 floors and Tower II with 32 floors
Number of garage floors	5
HVAC System	Chilled water, centrifugal chillers, variable flow on primary loop,
Building type/use	Office building; core and shell
Lighting power density	10 W/m²
Equipment power density	21.5 W/m²
Occupancy	7 m²/person



Tower I

Tower II

Figure 1 – Geometry of the building model.

Building occupancy was programed to occurs according to scheme presented in Figure 2. These data were obtained from information provided by the building owner. The use of lights and plug loads follows the time of occupancy, as the HVAC system availabilty also.

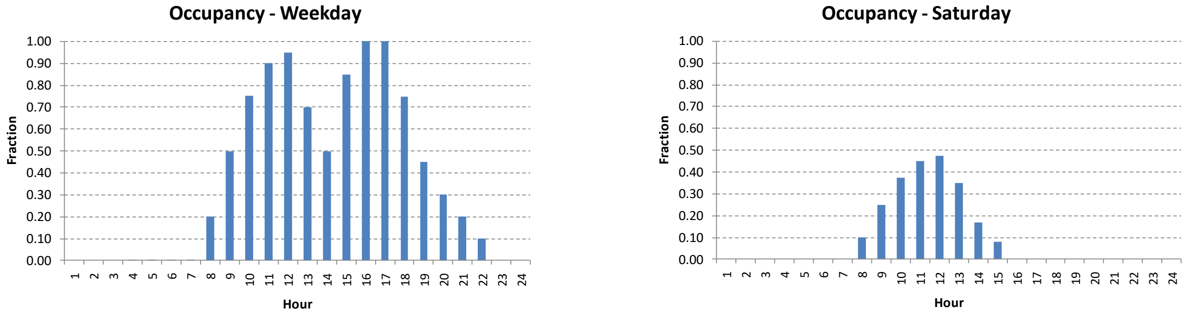


Figure 2 - Schedules of occupancy for Weekdays, Saturdays.

To support the design team in defining main characteristics of the building façade, some parameters were selected to be studied in the sensitivity analysis. The architecture office has limited the list of parameters possible to analyze as follows:

a) Type of glass;
b) The use of spandrel glass, i.e., if the façade will be fully glazed or not;
c) The window-to-wall ratio (WWR);
d) Construction type of wall.

For each parameter, the simulation team selected possible variation of values, according to common practice and intentions of the owner, from previous projects. The values chosen for test over each parameter are listed in Table 2. Combinatory analysis for all these parameters has resulted in 132 cases that were simulated. Results were processed according to annual energy use and, consequently, energy savings against the baseline building, modeled according to ASHRAE Standard 90.1 (ASHRAE, 2007).

Firstly, annual energy savings for each case was calculated. Secondly, the sensitivity analysis was applied over input parameters.

Table 2 - Parameters selected for sensitivity analysis task.

	ID	U-value (W/m².K)	SHGC
Type of glass	#1	5.60	0.40
	#2	5.60	0.38
	#3	5.73	0.31
	#4	5.73	0.37
	#5	2.53	0.34
	#6	2.69	0.30
	#7	5.67	0.36
	#8	5.67	0.38
	#9	5.67	0.46
	#10	1.64	0.29
	#11	1.85	0.31
Spandrel glass	Yes; No		
WWR	40%; 50%; 60%		
Wall construction	Masonry wall; steel frame		

The average energy savings provide for each parameter was adopted as performance index. Calculation was made according to Equation 1.

$$\overline{ES_{par}} = \frac{EC_{par_i} - EC_{BL}}{EC_{BL}} \times \frac{1}{n_{par}} \qquad \text{Equation 1}$$

Where:

$\overline{ES_{par}}$: average energy savings provided by one parameter;

ECpar$_i$: energy consumption for each case *i* in a group of cases with variations applied over each input parameter;

EC$_{BL}$: energy consumption of the baseline;

n: number of cases with variation in the parameter under analysis.

4. RESULTS

Annual energy savings provided by each building model, i.e., each configuration of building façade, is presented in Figure 3, in ascending order. From the sample of 132 cases, the most energy efficient building model has presented 10.8% of energy savings and the less efficient, 5.3%. This result means that from the list of choices that the design team can make over the façade, the influence on energy savings will be in order of 5.5 percentage points.

Evidently, as would be expected, the case with highest energy saving is the model with WWR equal to 40%, glass #3 (SHGC 0.31 and U-value 5.73), i.e., the glass with lowest Solar Heat Gain Coefficient from the laminated options. Insulated Glass Units (glass #5, #6, #10 and #11) did not provide significant reduction on energy consumption when compared to laminated glass with similar SHGC values. This behavior is always verified in this type of building in Brazilian mild climates, as in São Paulo city. In this case, the outdoor temperature is lower than the HVAC setpoint in most part of the year, thus when the façade is not receiving direct solar radiation, the glass helps to dissipate heat to outdoors.

Figure 4 shows the occurrence frequency of the outdoor air temperature in São Paulo during the working time, from 8 a.m. to 8 p.m. It can be seen that in 70% of the time the exterior air is under 24oC, which is the setpoint for cooling inside the building. It means that even with the HVAC system operating for cooling due to internal loads, the building façade may be transferring heat to exterior by conduction through the glass.

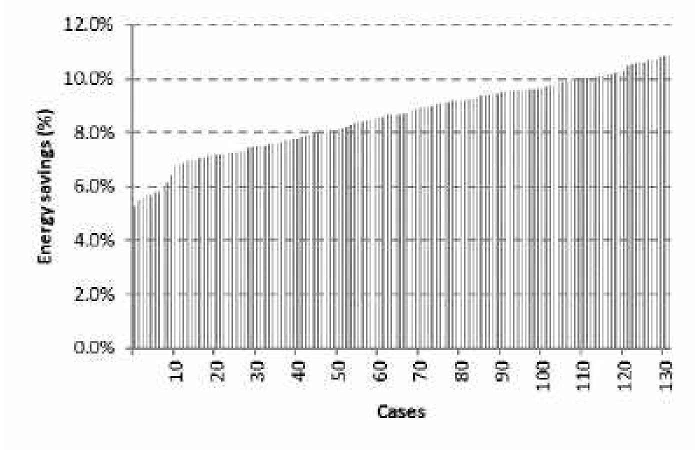


Figure 3 – Annual energy savings for each building model.

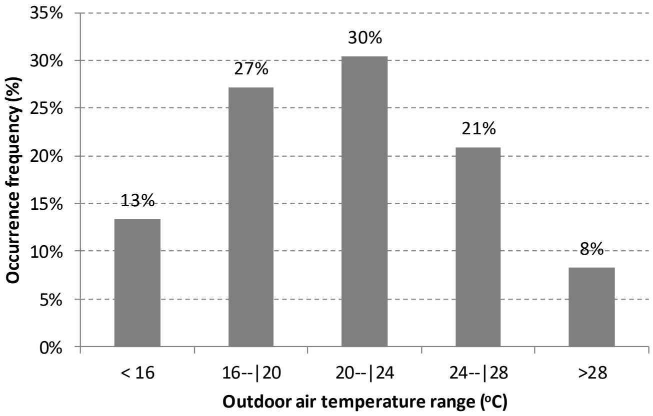


Figure 4 – Occurrence frequency of outdoor air temperature in São Paulo during working time.

Figure 5 shows the synthesis of the first step of the sensitivity analysis. The graph presents the average of percentage points of energy saving provided by the each parameters (middle point) and the highest (lower point) and lowest (upper point) variation over the entire simulation sample. Despite the known relationship between parameters in the annual energy consumption, the graphs try to isolate the contribution of each parameters in the total energy savings.

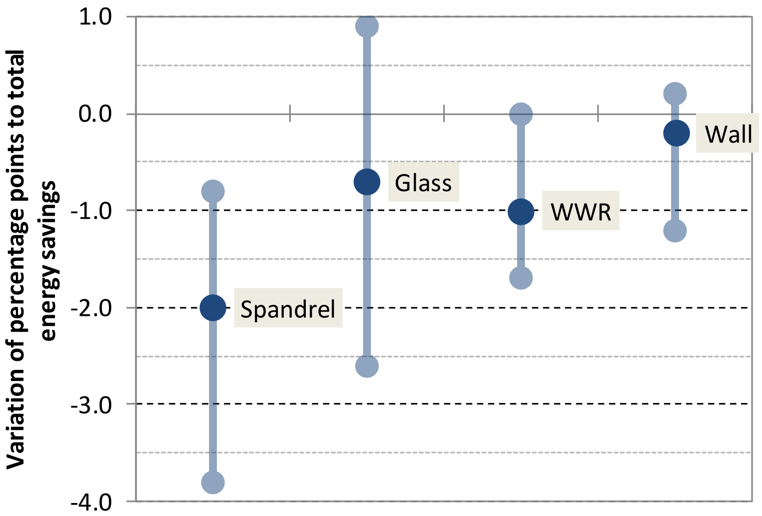


Figure 5 – Energy savings variation for each parameter.

The use of spandrel glass has demonstrated to be the most influent characteristic in the annual energy savings, with average of 2 p.p. (percentage points) of contribution in the annual savings. But, that parameters receives also significant influence from other building façade characteristics, as its lower and higher values are 3 points distant. This behavior means that the use of spandrel glass has huge influence on energy consumption of the building, but it is highly affected by other parameters under analysis, probably the type of glass and WWR. This type of conclusion is very helpful to design team, while explains that the building envelope features have to be defined in a holistic way, and not in a stepped process, where each parameter is defined at a time.

The use of spandrel glass causes the greenhouse effect in the façade, absorbing, accumulating and radiating the heat to indoor air. Even when installed in front of the building structure (Figure 6), the heat transferred to plenum add extra cooling load to air conditioning system. In tropical climate, this amount of heat can be significant.

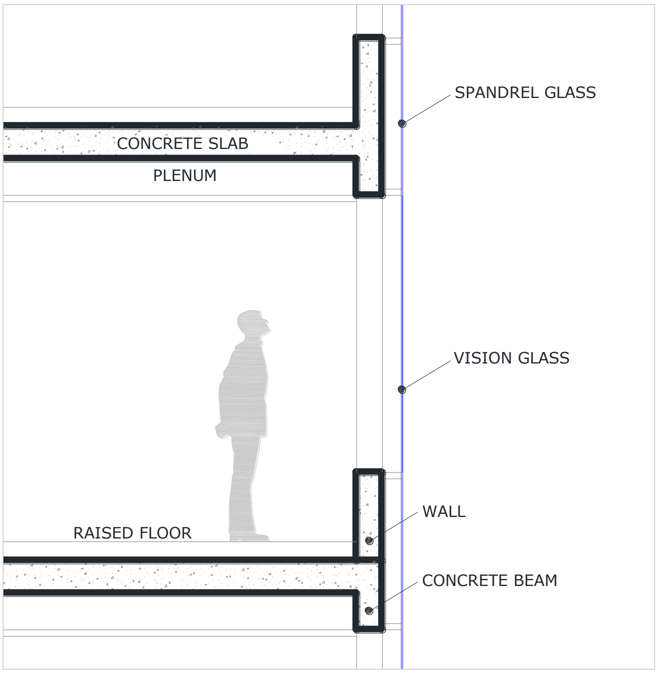


Figure 6 – Schematic design cut of the fully glazed façade.

The type of glass was the most dependent parameter from others. The variation on energy consumption due to changes on glass properties will depend mainly on window-to-wall ratio, but also the existence or not of the spandrel glass.

In the next step of the sensitivity analysis, the design team have taken some decisions over each parameter, according to their intentions and needs regarding aesthetics and economic issues. Characteristics has been defined in this order:

a) Type of glass: four types were selected from the first sample;

b) Spandrel glass: despite the high influence in the energy consumption, the architect and the project's owner have chosen for the fully glazed façade, due to aesthetical and maintenance reasons;

c) WWR: the design team, together with the owner, has decided to WWR 50%.

Selecting the models that satisfy those options above, energy savings variations were reduced to the intervals showed in Figure 7. The first set of models (that include all 132 simulation runs) resulted in 8.6% of savings in the average, with the best model achieving 10.8% and the worst 5.3%, as stated before.

After the selection of four types of glass only, the range of energy savings were restricted to 7.0%-10.8% (second bar in the graph), i.e., the best glass is included in this sample.

The option for the fully glazed façade, with spandrel glass in front of beams and columns, decreases the energy savings to 9.6% at maximum (third bar in the graph). Finally, the fourth bar shows the results obtained with the option for 50% of WWR, which has decreased the maximum economy to 8.7%.

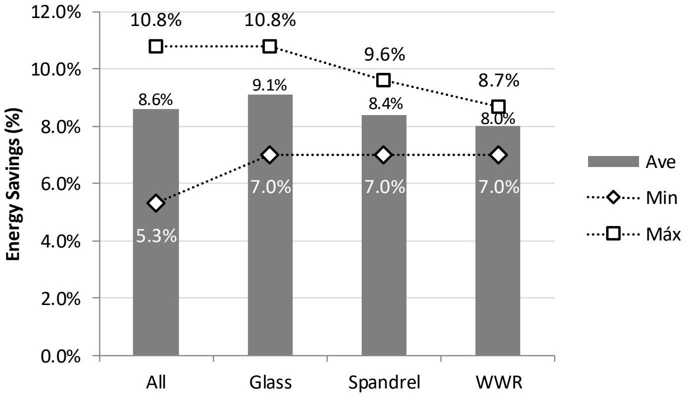


Figure 7 – Energy savings variations after each choice of façade characteristics by the design team.

As the energy performance goal was 10% of energy cost savings against the ASHRAE Std 90.1 baseline, the design team has decided to select other type of glass. A third batch of simulation runs was conducted.

The graph showed in Figure 8 shows the energy savings obtained for these new types of glass and another test was performed. Two levels of façade aperture, WWR 50% and WWR 40%, were evaluated. It can be seen that for these glazing specifications, the increase on window area has changed the energy consumption at maximum 0.8%. This means that when using a high performance glass, together with high efficient HVAC and lighting systems, the window area has a lower impact on energy consumption.

Figure 8 – Energy savings for cases with different glass types and WWR.

Analysis over the energy end-use of the model helps to understand the little impact of the façade configuration in the annual energy savings (Figure 9). The HVAC, that is the only system affected by the building envelope in this case, represents 24.8% (heat rejection, fan-coils, HVAC pumps and chillers) of annual energy use.

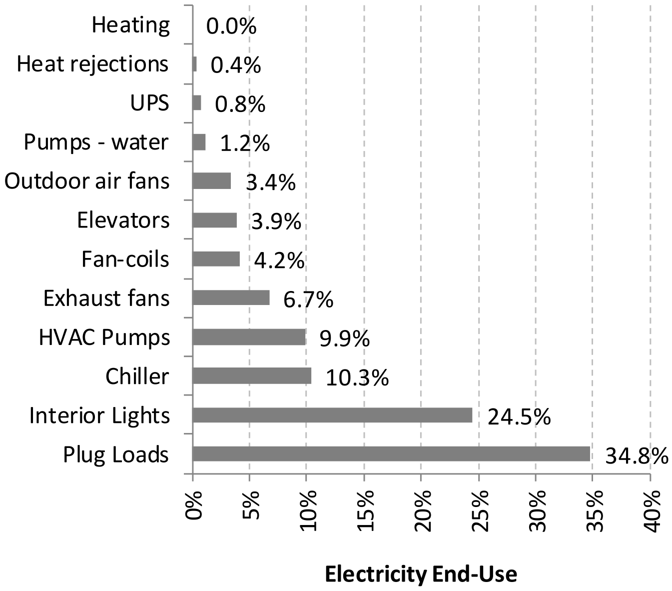


Figure 9 – Energy end-use of the building model with WWR 50% and glass type #4.

5. CONCLUSIONS

The use of fully glazed façade has become common in Brazil. Such a strategy has been always criticized, as in tropical climate, the solar heat gain through windows is very significant to cooling loads. Some architectural aspects has showed to have little impact on energy performance of the building.

At general, office buildings are designed according to landscape availability and economic issues. Variations in building shape and orientation are not available to design team, thus energy improvement of the project is restricted to building materials and façade configuration.

In this paper, a sensitivity analysis was conducted and a total of 132 building models were simulated with energy savings varying from 5% to 11% against the baseline building. Two other steps of sensitivity analysis were conducted to confirm that the façades of this type of building, with high performance glass, high efficient HVAC and lighting systems, have less impact on annual energy consumption.

The sensitivity analysis confirmed that for this building, with high performance glass, high efficient HVAC and lighting systems, the façade characteristics, such as window-wall ratio and glass type, have little impact on annual energy consumption.

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