SIMULATION AND ANALYSIS OF THE ENERGY PERFORMANCE OF AN OFFICE BUILDING LOCATED IN RIO DE JANEIRO – BRAZIL -

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ABSTRACT

This paper aims to analyze an office building energy performance at Rio de Janeiro.

Electrical power consumption profile of a building, resulting from a simulation using building energy-use simulation software, is obtained during a typical year and is shown on an hourly basis and pursuant to final uses. Thus, power consumption figures are obtained through the following final uses: lighting, office equipments, air conditioning and others. Analysis of this profile is accomplished by comparing existing technologies in the building, architectonical design solutions and building materials used, with the resulting power consumption figures evidenced during simulation. The consumption portion relative to air conditioning facilities is emphasized in this paper, since it's highly representative and offers a high potential of adequacy, from a viewpoint of equipment efficiency, and as a result of local thermal load factors.

After simulations, comparing the present building model with incremental situations in thermal resistance, both on facades and top-level floor, it was noticed that energy performance of building undergoes a large influence from facade protection. Glass covered areas, even featuring glass with satisfactory thermal resistance, is quite encompassing and produces a large impact on building global power consumption figures.

Based on this conclusion, an option was made to evaluate, in detail, impacts caused by different solutions to facade protection. Situations with varied hatching, change of glasses as well as glazed area were simulated and analyzed.

Lastly, this paper evidences the need to evaluate, still in a project phase, ~~of~~ the impacts on power consumption figures, resulting from a building materials choice and architectonical design solutions, which can be applied in the building.

Development of a culture which valuates energy-efficiency and which involves agents of this area, is extremely important: creation of an adequate legislation and designer awareness in order to avoid applying architectonical enclosure typologies that are inadequate for our climate, are goals to be attained.

KEYWORDS

Energy efficiency; Bioclimatic architecture; building energy-use simulation software; Commercial Buildings; Brazil

INTRODUCTION

Research investments in the energy efficiency sector are expanding along the years due to the growing human needs and current environment, economic and social restrictions. (La Rovere 2002). Energy efficiency is sought in all stages of the energy cycle: generation, transmission, distribution and the end-use of electric energy.

Electric energy consumption in buildings is very representative in the global consumption of a developing country (The Brazilian Energy Balance 2003), and is present in all sectors of national economy. Therefore, it is strategically interesting to do surveys, promoting awareness of the individuals involved and making feasible actions aiming at correct practices related to the energy efficiency in buildings, increasing thus the results broadness .

An energy efficient building must offer the user the same comfort conditions in environment terms with lower consumption of electric energy. Therefore, the classic Vitrúvio conceptual triangle - solidity, beauty and utility - may be added a vertex - the energy efficiency - turning it the ideal concept for the contemporary architecture. (Lamberts R et all 1997).

Historically, architecture has complied the principle of taking advantage of the climate favorable characteristics while avoiding the undesirable ones. For many decades, solutions that offered the use of daylight and ventilation as well as other solutions that brought along higher thermal comfort inside the buildings were widely adopted. The International Style, which has appeared in the period of time between wars, changed entirely the architecture concepts. Therefore, the indiscriminate use of this model has created the "greenhouse" building, where the entire envelope was composed of glass curtains, disregarding the local climatic characteristics. (Lamberts R., et all 1997).

Considering this new international architectonical model for office buildings that was also adopted by Brazil and having as an aggravating factor the Brazilian tropical climate, the continuing use of air conditioning in this type of building is necessary almost all year long. In view of this fact, in a large part of Brazil there is the need to reduce the solar gain in buildings, in order to mitigate the thermal load inside the building and, therefore, the air-conditioning consumption portion. The climate and its integration with the architecture, from the early stages of the building project have to be considered. (Tzikopoulos A. F.et all 2005).

This work aims to supply technical information for architects, engineers and experts that deal with commercial office building project, specially during early project stages. It's important to keep in mind that the energy-use reduction reaches much higher levels when the survey is done in the initial project stage. Design options, such as orientation changes and some bioclimatic solutions, may no longer be adopted after building construction is finished.

METHODOLOGY

At first, technical visits were made to collect building data - architectonical and complementary projects plants, interviews with the building maintenance and administration personnel, in loco measurement and observations, etc. Such information was processed and organized to be inserted in the simulation program.

Among the data required to the creation of the building model, it's important to be acknowledged with:

- Local climatic conditions;
- Building geometrical characteristics;
- Geographic orientation of the construction and the existing external shading elements - trees, other constructions, *brise soleil*, etc;
- Different materials - glasses, top-level floor, facades, etc - used in the envelopes as well as its thermal characteristics;
- Building uses and its occupation schedules;
- Air-conditioning system characteristics; as well as conditioned and not conditioned places and the periods this system is used in each environment;
- Lighting system characteristics and the installed power.

Through the use of simulation software, a building model was created; based on this model, architectonical modifications were simulated

This building energy-use simulation software uses its own climate data file. Such files, including yearly climate data are achieved, in general, from local airports data, from a statistical approach. In this work, the data file used was in the TRY [1] format. Information related to the building external air are characterized by means of hourly data of dry bulb and wet bulb temperature, atmospheric pressure, enthalpy, density, humidity, wind direction and speed, normal and horizontal plan direct radiation, air fog rates, types of clouds, occurrence of rain and snow. (http://www.labeee.ufsc.br/arquivos/arquivos_climaticos_2005).

After model creation, the calibration is performed with the help of measurements taken place in the existing building and electric energy bills supplied by the management. After model calibration, a few initial simulations were performed, with the single purpose of evaluate the building sensitivity as to the changes in the envelope, which are, in this case, specifically related to facade and top-level floor.

After this initial analysis, different situations were simulated, such as glass exchange, use of external protections, replacement of glass curtain by masonry in the windows, etc. At this stage, the building energy behavior is evaluated, which is the purpose of this paper.

SIMULATION

Description of the simulated building

The simulation was performed in a services office building, in a commercial condominium in the West Area of the Rio de Janeiro Municipality, latitude 22°49´S, longitude 43°15´W, tropical climate, with average temperatures from 21,1 °C to 27,3 °C. The front facade has a 5° orientation to the geographic North, towards the West, corresponding to azimuth 175°. The facades include laminated glass panels, reflective green color, with some external protection given by some trees and a close building (figures 1 and 2). Inside each building block there is a central open atrium where one of the stairs is located.

[1] TRY, from the English, *Test Reference Year*, refers to a full and real climatic year, selected among 10 available climatic years, as the one with the best balanced data with no extremes in terms of maximum and minimum.

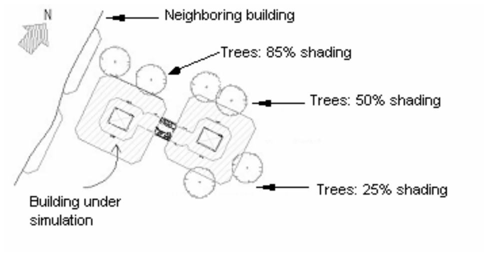

Figure 1: Floor plan of the simulated building with existing shadings

It's a low height building, of about 15m, with 5 levels, being the height from level to level of 2,90m and total built area of 6.627m². Opening hours are the standard for service office buildings: Monday thru Friday, from 8 am to 5 pm

Figure 2: External view of the facades

The building has permanent artificial acclimatization, and the main air conditioning system comprises fan coils provided by a cold-water center shared by the condominium, operating in the hours above mentioned. As the data center runs 24 hours a day, one additional air-conditioning self contained unit's used. From simulation it's to be observed that the air conditioning system is responsible for a significant parcel of the total energy consumption in the building, approximately 63% (Figure 3)

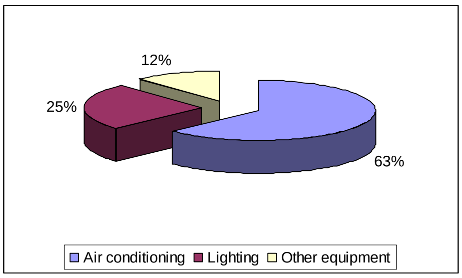

Figure 3: Distribution of the energy consumption by end-use.

Case study

A number of simulations were performed with the purpose of identify the building sensitivity under study as to alterations in the facade and roofing.

Roofing alterations in the existing building

The top-level floor terrace is exposed to direct solar radiation, as originally it did not have any type of protection. It takes the entire top-level floor area, with 5,40m and 6,00m width. The existing floor is made of a 5cm sub floor covered with anti-sliding ceramics, 10cm reinforced concrete structural slab of light color. Inside the building there is a ceiling with plenum for the air conditioning return.

Two simulations were performed replacing the top-level floor: one of the modifications proposes to add, in the composition, a expanded polystyrene plate, one on the top and another below the slab, with 2cm of cement mortar in both sides. The other one was the replacement of the floor by a green roof (turfing).

On the roof, the option was to replace the existing cover, made of aluminum tiles internally filled with expanded polyurethane, by a green roof.

According to Ekaterini (1998), the total solar radiation absorbed by planted covering splits as follows: 27% is reflected, 60% is absorbed by the plants and the soil through evaporation, and 13% is transmitted into the soil. The absorbed value of solar radiation for a vegetated covering is about 0,3 (Eggenberger A. 1983).

Plants can protect the roof from the thermal loads of solar radiation in three main ways: their reflective properties, the convection of energy absorbed by the plants, and the evaporation from the plants and soil. (Eggenberger A. 1983)

Facade alterations in the existing building

It was decided to perform two simulations with external shades, as follows: inclusion of trees to shade the Northeast and Northwest facades, that were picked as they suffer greater direct solar incidence and are not much protected by trees or close buildings. Shading devices (*brise soleil*) were used with solar factor of 0,14 in all facades.

Three additional simulations were performed exchanging the existing glass panel for different types of glasses with the purpose of comparing the savings resulted from different thermal characteristics. Therefore, the simulation was the replacement of the existing transparent and green 6mm laminated glass by double transparent glass, with the technical characteristics provided on Table 1.

DISCUSSION AND RESULT ANALYSIS

From tables 2 and 3 it's possible to say that the building consumption suffers more influence from the facade alterations.

Solutions for the top-level floor (Table 2):

When the simulation includes expanded polystyrene plates in the top-level floor or the replacement of the floor by slabs with vegetated cover, the reduction is only 0,54% and 0,51%, respectively, in the consumption of electric energy, overall in the building. Such situation takes place because the floor is light colored (low absorption, 40%) and it is somewhat shaded by the roof itself. This reduces the heat that reaches the floor surface. Additionally, the conditioned environment below has a plaster ceiling, i.e. it already has a low thermal transmittance. Therefore, the solutions that propose reduced thermal transmittance in this place tend not to show high performance gains. However, shading solutions exhibit better performances than addition of insulating materials. Simulations using pergolas in the top-level floor terrace exhibited reductions of 2,65% and 3,98% in the building overall electric energy consumption, for pergolas of 2,5m and 4m respectively. The results achieved are more remarkable as in these cases there is a reduction of the direct solar radiation that reaches the top-level floor terrace. It's noteworthy that preventing the radiation to reach the closure (opaque or transparent) is much more efficient, for the following reason: initially, the external surface received the heat by convection and radiation, when the increase in the surface temperature occurs. In a second stage, through conduction, the heat flow starts; only at this moment the thermal resistance increase of the closure reduces the entrance of heat inside the building. The thermal resistance increase may not be effective at this point, since the building envelope has already absorbed the heat.

To simulate the planted roof covering, the following data were used (Corbella 1999):

- Vegetate absorbance was defined by 40% and the roughness, 1;
- For the moisturized land: Specific mass (kg/m^3) = 1800, Conductivity (W/m/ºC) = 0,580, Specific heat (J/kg/ºC) = 1460.

Another alternative tested was the replacement of the top-level tiles by vegetated covering, and the reduction was negligible. This may be explained by the fact that the existing aluminum tiles filled with expanded polyurethane supply good insulation. Therefore a good solution, such as the vegetated cover, had nearly the same result.

Of course, beyond the thermal capacity, the green roof shows several other positive features associated to is fabrication and use, being noteworthy: improvement in the building aesthetics; acoustic problems reduction ; improvement of the local micro climate; it does not require energy intensive materials in its manufacturing.

Table 1: Technical data of the simulated glasses

Glass	Shading Ratio	Lighting Transmission	Thermal Transmittance U factor-W/m²
6mm colorless glass	0,95	0,881	6,17
6mm green colored glass	0,71	0,749	6,17
SS08 (base case) 6mm colorless glass	0,23	0,08	4,9
SS08 6mm+air+double colorless glass	0,15	0,073	2,26

Solutions for the facade (Table 3):

By simulating trees giving major shading on the NE and NW facades, there was a reduction of 1,85% in the building overall electric energy consumption, once again evidencing the importance of the envelope external shading. It's observed that this solution is a feasible solution once the building is not higher than 15m.

Now, the inclusion of shading devices is feasible in lower as well as taller buildings. In the building under survey, shading devices with solar factor of 0,14 (only 14% of the direct solar radiation that impacts the device crosses it and reaches the closure) allow for a reduction of 3,93% and 2,42% of the building overall electric energy consumption when used in all facades and only in the Northwest and Northeast facades, respectively. This sun baffle may be horizontal or vertical, however dimensioned to comply with the specific solar factor. It's also possible to use a steel structure with absorbing cloth under the requested solar factor.

A simulation set was performed in order to evaluate the impact caused by the type of glass and also by a larger or smaller glassy area. At first, the glass panel was kept and the existing glass was replaced by three other types of glass and the following results were achieved: increase of 11,79% and 8,68% of the building overall electric energy consumption using transparent glasses of 6mm and green glasses of 6mm, respectively. A reduction of 1,55% was obtained in the building overall electric energy consumption using double glasses, similar to the existing ones. The results interpretation is based on the glasses thermal characteristics, exhibited on table 3.

Then, by replacing the existing glasses by a transparent one, with same thickness, there is a significant increase in the building energy consumption.

Table 2: Results of the top-level floor alternatives simulated in the Building energy-use simulation software

Top Level Alternatives	Reduction/ Increase	
	% Air Cond	% Total
Inclusion of two polystyrene plates in the top level floor slab	-0.87%	-0.54%
Replacement of the top level floor by a green cover.	-0.83%	-0.51%
Placement of pergola (2,5m) in the top level terrace	-4.27%	-2.65%
Placement of pergola (4m) in the top level terrace	-6.40%	-3.98%
Alternatives of Facades	**Reduction/Increase**	
	% Air Cond	**% Total**
Protection of the facades northeast and the northwest for trees	-2.97%	-1.85%
Use of sun break in all the facades	-3.92%	-2.42%
Use of sun break in the sunniest facades (NW e NE)	-6.35%	-3.93%
Substitution of the existing glass by 6mm transparent plated glass	18.97%	11.79%
Substitution of the existing glass by 6mm green plated glass	13.96%	8.68%
Substitution of the existing glass by double glass	-2.49%	-1.55%
Substitution in 60% of existing glass area by masonry	-4.99%	-3.10%
Substitution in 60% of existing glass area by masonry and substitution of the existing glass in the remaining 40% by 6mm transparent glass plated	3.26%	2.03%
Substitution in 60% of existing glass area by masonry and substitution of the existing glass in the remaining 40% by 6mm green glass plated	0.21%	0.13%
Replacement of roof tiles at the top level by nature cover	-0.01%	0.00%
External protection of center prisms with awning-like protection	-3.59%	-2.23%

Table 3: indicates the facades alternatives simulated in the building energy-use simulation software as well as its results.

CONCLUSION

The results obtained in the simulations show the importance of shading, i.e. to prevent direct solar radiation from reaching the building envelope. Therefore, a good approach to building design in such case is to adopt solutions that reduce the solar radiation effects, through shading, low thermal transmittance or any other choice with this purpose.

It is also very important to select an adequate glass, specially in buildings that have glass panels, where the glass area is large, as the impact in the electric energy consumption is actually strong. The greenhouse effect have to be avoided and, whenever possible, the direct solar radiation must be blocked before it penetrates the glass.

It is important to remind that the best results are certainly in the project initial stage, when the architecture solution is being defined, once at this time, the shading elements may be inserted in the building in a harmonious and energy efficient way.

Works on the application of vegetation in architecture in Brazil should be developed in the future. A quantity analysis related to reflection and solar radiation absorption when vegetation is employed in the external surfaces is also needed.

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