RESEARCH ARTICLE OPEN ACCESS

Influence of Glazed Façades on Energy Consumption for Air Conditioning of Office Buildings in Brazilian Climates

Fernando Simon Westphal[1], Cínthia Andreis[2]
[1,2]Department Of Architecture And Urbanism, Federal University Of Santa Catarina, Brazil

ABSTRACT
The energy performance of buildings is defined by their electrical systems and thermal exchanges through the envelope, mainly by glazing systems. This study evaluates, through computer simulation, the influence of glazing façades in the energy consumption of the air conditioning system of an office building in five Brazilian cities with different climate conditions. A computer model was developed to analyze the influence of window-to-wall ratio, type of glass and façade configuration in the energy need for air conditioning. The results show that the energy performance of the building is highly influenced by the configurations of the façade, mainly by glazed elements. In cold climates, high thermal transmittance of the envelope helps the dissipation of internal heat gains, reducing energy consumption for air conditioning. In this case, the use of insulated glass unit can be unhelpful. Furthermore, the opening area causes energy consumption variation up to 27.5% depending on climate and type of glass. But the use of a high selective glazing system can decrease the energy need for cooling when the window area is increased.
Keywords: Glazed façades, energy consumption, Brazilian climates, office building.

I. INTRODUCTION

Buildings are responsible for 47% of total electricity consumption in Brazil [1]. In the recent years, new commercial buildings have been designed with fully glazed façades. This type of architecture has been criticized by its application in hot and humid climates, which is dominant in most part of this country.

The main reasons for the adoption of fully glazed façades consist of: transparency and visual integration with the outdoors, daylight admission, and aesthetic request from designers and investors [2, 3].

In the context of commercial buildings, many authors point out the air conditioning system as responsible for major participation in annual electricity consumption [4]. In a study carried out for hot arid areas the fully glazed façade was responsible for 45% of the building cooling load [5].

The participation of the air conditioning system in the energy consumption of the building depends effectively on factors such as coefficient of performance (COP) of the system, internal loads density and pattern of use, and building envelope configuration.

Authors have been highlighted the increase in the glass area of the façades in Brazilian office buildings since the 1970s [6, 7]. In the 1990s, due to growing concern about global warming, there has been an increased demand for energy-efficient buildings, driving the development of new solutions and technologies. Among the main features of these high tech buildings are open plan office spaces, flexibility of use, high degree of automation and management systems, high efficiency air conditioning systems and fully glazed façades with high selective glazing systems [7, 8]. Office towers with glass skin, without any shading devices, are increasingly common in Brazilian urban centers of different climate conditions. In the last decade, glass has been adopted as one of the most important materials for the design and construction of commercial buildings in this country [3, 6, 9].

The elements of glazed façades influence the energy consumption of the air conditioning system, varying according to: orientation, window-to-wall ratio, type of glass and solar protection (internal or external), as they allow part of the solar radiation to be easily transferred directly into the building [10].

This study has the general objective to evaluate, by computer simulation, the influence of different configurations of façades in the energy consumption of the air conditioning system in an office building for different Brazilian climate conditions. The parameters under evaluation are: window-to-wall ratio (WWR), glass type, wall construction, façade configuration (fully glazed or not) and climate.

II. METHODOLOGY

The method is based on the use of EnergyPlus simulation software [11]. The procedure consists on to create a base case replicated a number of times, changing one variable at a time to obtain results relating to each parameter under analysis.

The influence of parameters window-to-wall ratio, type of glass, façade setting and location is evaluated based on the total annual energy consumption of air conditioning system (heating and cooling). The use of daylighting and energy consumption for artificial lighting system was not taken into account.

II.1 Simulation model

A base case building has been adopted from previous work from the same research team [12]. The features of the simulation model are presented in Fig. 1, representing a rectangular shaped conditioned office building, with open plan spaces, divided into five thermal zones, with 20 floors total. Peripheral areas are conditioned and correspond to office spaces. Services areas are unconditioned and located in the center core zone. The four façades have identical conditions of window-to-wall ratio, construction and type of glass. The base building retains certain invariable features, i. e., geometry, geographical orientation, internal loads, pattern of use and occupancy, roof, floors, interior and exterior walls, as described in Table 1.

Fig. 2 shows the schedules of occupancy adopted in the building model to simulate its pattern of use along the days. The operation of the lighting system, plug loads and air-conditioning follows the same pattern of occupancy. No building use is considered on Sundays and holidays.

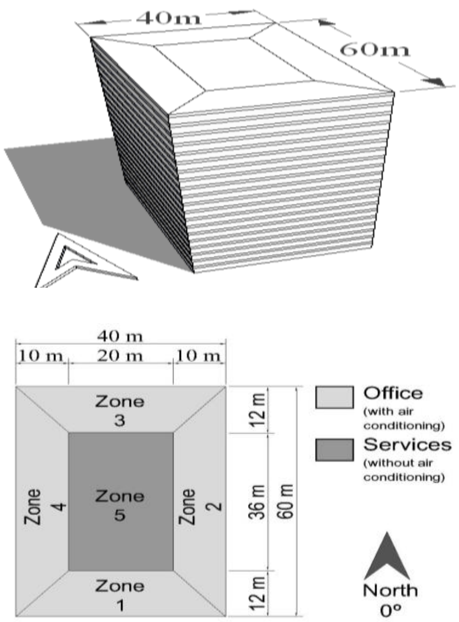

Figure 1 – Simulation model geometry.

Table 1 – Main characteristics of the base case simulation model.

Total floor area: 48,000 m² Conditioned area: 36,000 m² Dimensions: 60 m (depth) x 40 m (width) Core: 36 m (depth) x 20 m (width) Floor to floor height: 4.0 m Plenum height: 1.2 m Floors: 20 Façade area: 16,000 m²
Exterior wall construction: masonry wall with clay blocks 250 mm; U-value 2.66 W/m².K Floors: concrete slab 200 mm Roof: concrete slab with thermal insulation insulation (U-value 0.58 W/m².K)
HVAC System: chilled water with VAV boxes; centrifugal chillers COP 6.10 W/W. Thermostat settings : 20ºC heating; 24ºC cooling
Shading devices: interior blinds; closed at 200 W/m² of incident solar radiation. Occupancy: 8m²/person; metabolic rate: 117 W/person Lighting power density: 12 W/m² Plug loads density: 16 W/m² Outdoor air rate: 0.0075 m³/s Other electric loads on common areas: 231 kW (15% of total energy consumption)

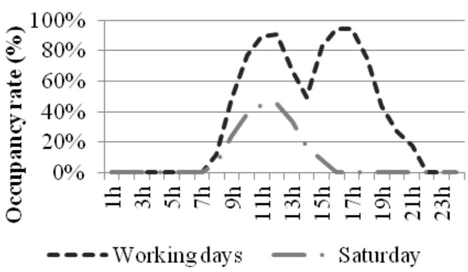

Figure 2 – Building occupancy schedule.

II.2 Parameters under analysis

Studies on thermal performance of glazed façades confirm the importance of proper specification of their elements according to the climate conditions of the building location. In Brazil, investigation about the influence of WWR, glass type and thermal transmittance of opaque constructions were developed by [12, 13, 14, 15, 16]. In the international scenario, studies by [17] in Italy, [18] in Mexico, [19] in Tunisia, [20] in Portugal and [21] in Norway, analyzed the effects of changing the glazing type and thermal transmittance of exterior walls in the building energy consumption for different locations and climates. Studies about buildings that use glazed skins as the final covering of the façade demonstrate that this type of solution creates greenhouse effect between the glass and opaque construction that contributes to building overheating. This can be helpful on cold climates but can be adverse on hot climates [2, 5].

Based on the main factors that impact the energy performance of buildings, variables analyzed in this study were determined according to Table 2. The factorial sampling of cases modeled to vary each parameter at once has resulted in 128 simulation runs.

The base case model has 4.0 m of floor-to-floor height. Window area was disposed along the width of each façade and the window-to-wall ratio was varied from 30% to 60% by increasing window height, as showed in Fig. 4.

Four types of glass were considered in this study: single clear, single green, laminated solar selective glazing and insulated glass unit (IGU) with selective glazing, 12.5 mm air gap plus single clear as interior layer. Main optical and thermal properties of each configuration are presented in Table 3. The table shows also, in the last column, physical characteristics of the white glass used as coverage of exterior walls for those models simulated with glazed skin façade.

Thus, two façade configurations were simulated: conventional façade setting, with the wall exposed to outdoor environment (Fig. 5); and glazed skin façade, with white glass covering exterior walls (Fig. 6).

Table 2 –Parameters under analysis.

Parameter	Values	
Window-to-wall ratio (WWR)	30%	
	40%	
	50%	
	60%	
Glass type	Clear	Single clear glass
	Green	Single green glass
	Selective glazing system	Solar selective coated glass, laminated
	Insulated glass unit	Double glazing unit with solar selective glass + 12.5mm air gap + clear glass
Façade configuration	Conventional (wall exposed)	
	Glazed skin façade	
City	Curitiba (PR)	
	São Paulo (SP)	
	Brasília (DF)	
	Rio de Janeiro (RJ)	
	Salvador (BA)	

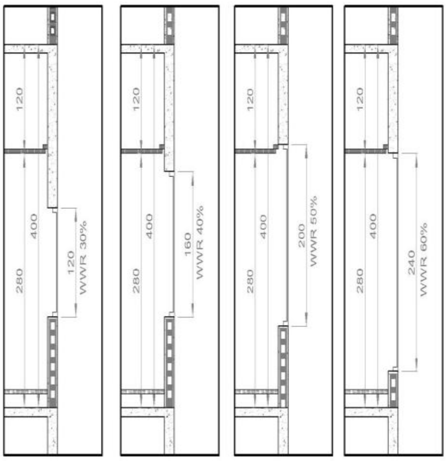

Figure 4 – Schematic sections of window-to-wall ratio modeling strategy.

Table 3 – Thermal properties of types of glass under analysis.

Parameter	Single Clear	Single Green	Selective glazing	Insulated Glass Unit			Glass skin
				Ext glass	Int. glass	Total	
Thickness (mm)	12	12	12	6	6	6+12.5+6	10
Light transmittance (%)	86	75	30	44	88	39	12
U-value (W/m²K)	5.60	5.60	5.60	5.60	5.60	1.88	5.60
Solar heat gain coeff. (%)	77	62	38	35	84	28	30

The Brazilian territory is wide extent and presents different climate conditions. For this reason, five cities were selected to conduct this analysis, covering different climate variations along the country. Table 4 shows the list of selected cities, with their geographic location, average air temperature and degree-hours of cooling at base 24°C and degree-hours of heating at base 20ºC. Degree-hours of cooling (DHC) is the sum of difference of the outdoor air temperature and the base 24ºC, when it is higher than 24°C. Degree-Hours of heating is calculated in the same way, but considering the difference of temperature between the base 20°C and the air temperature.

Table 4 - Geographical and climatic data for the cities under analysis.

Cidade	Curitiba	Sao Paulo	Brasilia	Rio de Janeiro	Salvador
Latitude	25.5°S	23.6°S	15.8°S	22.8°S	13.0°S
Longitude	49.2°W	46.6°W	47.9° W	43.2°W	38.5° W
Altitude [m]	910	802	12	5	51
T_{ave} [ºC]	16.3	18.0	21.5	23.7	26.0
DHC_{24} [ºC.h]	2,096	4,059	7,105	10,529	18,415
DHH_{20} [ºC.h]	32,853	18,142	10,537	1,312	6

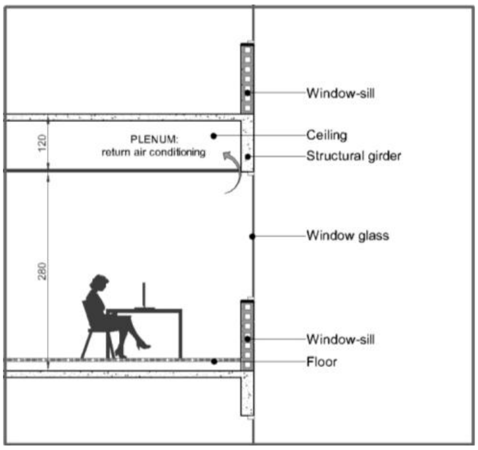

Figure 5 – Schematic section of conventional façade, without glass skin.

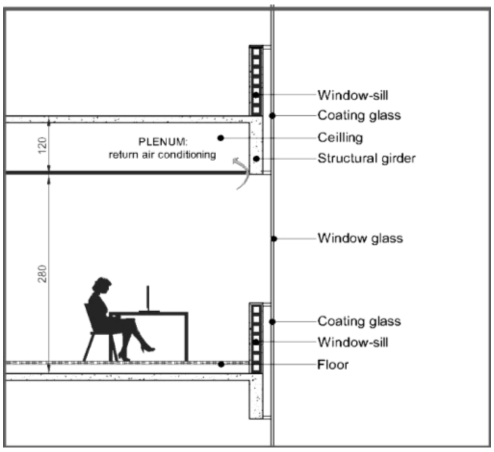

Figure 6 – Schematic section of glazed skin façade.

III. RESULTS AND DISCUSSIONS

Data of cooling energy consumption of the set of 64 cases simulated with conventional façade configuration (without glazed skin) are presented in Fig. 7. The graph shows clearly that the energy consumption increases, as the climate gets hotter, i.e., Salvador presents the highest energy use. It is also evident the growth in electricity use linearly with the increase in WWR. Nevertheless, the influence of type of glass in the energy performance of the building is not linear. The glass types were chosen with improvement in the SHGC (Solar Heat Gain Coefficient).

With lower SHGC, better is the glass for Brazilian climates, because lower will be the need for cooling. However, changing from laminated glass to IGU (Insulated Glass Unit), even decreasing the SHGC from 0.38 to 0.28, the energy need for cooling has increased for all cases in Curitiba and Brasilia. In Sao Paulo, the performance of cases with IGU was almost the same of cases with laminated glass.

This behavior confirms that for some types of climate, building design and use, the thermal insulation of the façade cannot lead to any improvement in the energy performance of the building. In extremely hot climates, such as Rio de Janeiro and Salvador, the use of IGU brings minor benefits.

The glazed skin façade presented higher energy consumption for cooling than those options with exterior walls exposed to outside air. The greenhouse effect provided in the air gap between the glass layer and the exterior wall had increased the cooling demand of the building for all configurations of façades and climates.

The graph on Fig. 8 shows the percentage of increment in the energy consumption for each of the 64 cases simulated with glazed skin façade against the other set of 64 cases, without glazed skin. It can be noticed that the influence of glass covering in the façade is most significant in colder climates, such as Curitiba, São Paulo and Brasilia. For hot climates, the influence of solar radiation on the façade is minimized by the influence of heat gain due to difference of temperature between outdoor and indoor environments. This increments in energy consumption was higher than 20% in Curitiba, for those cases with higher exterior wall area, i.e., WWR equal to 30%.

As the building has other important sources of heat gain, the increase on window area may not represent a significant growth in the energy consumption for cooling. The graph of Fig. 9 shows the relative increase of energy consumption from cases with WWR 60% to cases with WWR 30%, considering building models without glazed skin. It can be seen that when using clear glass the increment on energy consumption can overcome 25% in Curitiba and Brasilia. But when using selective glazing systems in hot climates, such as Rio de Janeiro and Salvador, the double of window area increases the energy consumption for cooling up to 10%. Therefore, this result confirms that window aperture can be increased with the use of a high selective glazing system to minimize the increase on energy consumption.

When using glazed skin façade, the increment on energy consumption due to higher WWR is lower, as shown in Fig. 10. In this case, the growth in need for cooling can be lower than 5% in Rio de Janeiro and Salvador, when using selective glazing systems and doubling the window area.

.

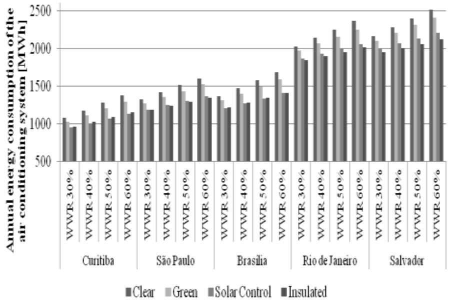

Figure 7 – Annual energy consumption for cooling (MWh) of building models with conventional façade as function of WWR, type of glass and climate.

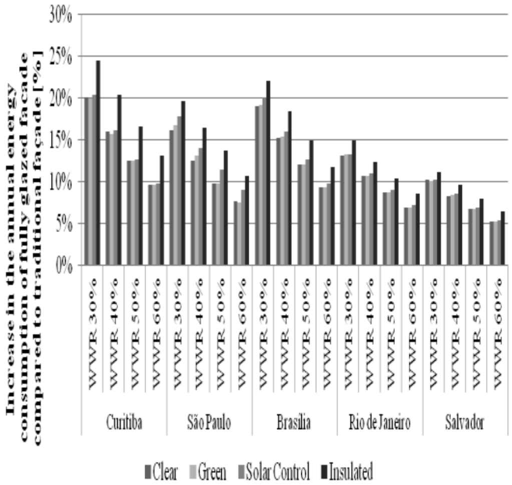

Figure 8 – Increase in the annual energy consumption of fully glazed façade compared to conventional one as function of WWR, type of glass and climate.

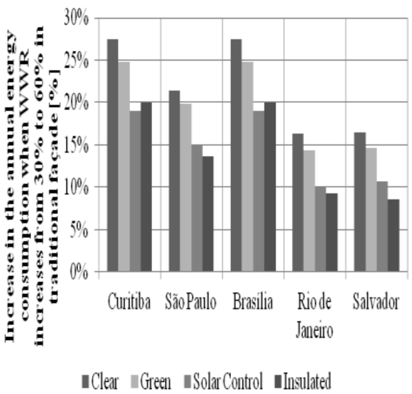

Figure 9 – Increase in the annual energy consumption when WWR increases from 30% to 60% in conventional façade for each city and glass type.

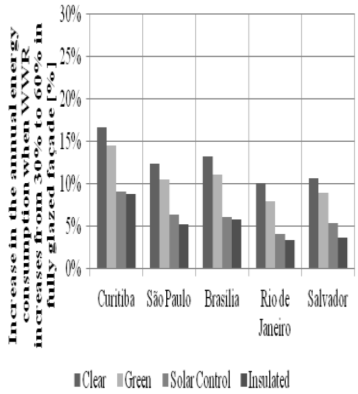

Figure 10 – Increase in the annual energy consumption when WWR increases from 30% to 60% in fully glazed façade for each city and glass type.

IV. CONCLUSION

This paper presents an analysis of the influence of glazed façades configuration in the energy consumption of an office building in five Brazilian cities. The analysis was conducted through computer simulation by using of EnergyPlus software. A set of 128 parametric simulation runs was carried out covering different configurations of façades and climates.

The energy consumption for cooling was confirmed linearly dependent on the window area for all climates under analysis. But the level of influence of the glazed area on energy consumption depends on other factors, such as type of glass and type of façade covering. Selective glazing systems, with Solar Heat Gain Coefficient (SHGC) lower than 40% has provided better energy performance for the building envelope. The window area can be significantly increased when using more efficient glazing systems, with low impact on energy consumption on hot climates.

The glazed skin façade showed to be less efficient than those configuration without the glass covering over opaque walls. This behavior was confirmed for all climates under analysis, with higher influence on coldest climates, which experience more impact from solar radiation into the building than the heat gain due to difference of temperature between inside and outside. The greenhouse effect provided in the air gap between glass covering and exterior wall increased the energy need for cooling.

The use of Insulated Glass Unit (IGU), i.e., double glazing systems with air gap, showed to be unhelpful in colder climates, even for those building models with high window area. For this type of building design and climate the choice for more insulated envelope can avoid the heat dissipation through the façade, thus the use of monolithic or laminated glass is more suitable.

The conclusions obtained in this research applies only to the building model characteristics under analysis. Similar assessment to other building types and climates can be made with caution. The use of detailed computer simulation is recommended to define the influence of the architecture decisions in the energy performance of buildings.

REFERENCES

[1]. EPE - EMPRESA DE PESQUISA ENERGÉTICA. Balanço Energético Nacional - BEN. Available at: <ben.epe.gov.br>. Acessed: Jun. 8th 2013. In Portuguese.
[2]. GRATIA, E.; DE HERDE, A. Greenhouse effect in double-skin facade. Energy and Buildings, v. 39, n. 2, p. 199–211, fev. 2007.
[3]. SHAMERI, M. A. et al. Perspectives of double skin façade systems in buildings and energy saving. Renewable and Sustainable Energy Reviews, v. 15, n. 3, p. 1468–1475, abr. 2011.
[4]. CARLO, J.; LAMBERTS, R. Development of envelope efficiency labels for commercial buildings: Effect of different variables on electricity consumption. Energy and Buildings, v. 40, n. 11, p. 2002–2008, jan. 2008.
[5]. NEVEEN, H. Double versus single skin facades in hot arid areas. Energy and Buildings, v. 40, n. 3, p. 240–248, jan. 2008.
[6]. ROMERO, A.; GONÇALVES, J. C.; DILONARDO, L. F. P. A evolução da arquitetura e dos aspectos energéticos dos edifícios de escritórios nos últimos 30 anos na cidade de São Paulo. ENCAC. Anais... Fortaleza, CE: ENCAC, 1999. In Portuguese.
[7]. MARCONDES, M. P. Soluções Projetuais de Fachadas para Edifícios de Escritórios com Ventilação Natural em São Paulo. [s.l.] Universidade de São Paulo, 2010. In Portuguese
[8]. MARQUES DA SILVA, F.; GLÓRIA GOMES, M. Gap inner pressures in multi-storey double skin facades. Energy and Buildings, v. 40, n. 8, p. 1553–1559, jan. 2008.
[9]. MARCONDES, M.; ALUCCI, M.; GONÇALVES, J. Façades and office buildings in São Paulo (Brazil): aiming for thermal comfort and natural ventilation. 7a Windsor Conference: The changing context of comfort in an unpredictable world. Proceedings...London, UK: 2012. Available at: http://nceub.org.uk
[10]. PALMER, C. M.; GENTRY, T. A Better Distinction for Standard Specifications of Low-E Coatings for Diverse Climate Conditions. PLEA. Proceedings...North Carolina at Charlotte USA, 2012
[11]. U.S. DEPARTMENT OF ENERGY & RENEWABLE ENERGY. EnergyPlus, 2012. Available at: <http://apps1.eere.energy.gov/ buildings/energyplus/>
[12]. BESEN, P.; WESTPHAL, F. S. Uso de vidro duplo e vidro laminado no Brasil: avaliação do desempenho energético e conforto térmico por meio de simulação computacional. ENTAC. Anais.. .Juiz de Fora, MG: 2012. In Portuguese.
[13]. CARVALHO, M. M. Q.; LA ROVERE, E. L.; GONÇALVES, A. C. M. Analysis of variables that influence electric energy consumption in commercial buildings in Brazil. Renewable and Sustainable Energy Reviews, v. 14, n. 9, p. 3199–3205, dec. 2010.
[14]. MELO, A. P.; LAMBERTS, R. Envelope insulation and heat balance in commercial buildings. Proceedings of Building Simulation 2009, p. 2243–2250, 2009.
[15]. PEDRINI, A.; SZOKOLAY, S. Recomendações para o desenvolvimento de uma ferramenta de suporte às primeiras decisões projetuais visando ao desempenho energético de edificações de escritórios em clima quente. Ambiente Construído, v. 5, n. 1, p. 39–54, 2005. In Portuguese.
[16]. SALDANHA, A. M. Desempenho térmico e eficiência energética em edifício de escritório: análise do uso de fachadas de vidro diretamente expostas à radiação solar na cidade de Cuiabá-MT. [s.l.] Master Dissertation. Universidade Federal de Mato Grosso, 2012. In Portuguese.
[17]. BURATTI, C. et al. Unsteady simulation of energy performance and thermal comfort in non-residential buildings. Building and Environment, v. 59, p. 482–491, jan. 2012.
[18]. NOH-PAT, F. et al. Thermal analysis for a double glazing unit with and without a solar control film (SnS–CuxS) for using in hot climates. Energy and Buildings, v. 43, n. 2-3, p. 704–712, fev. 2011.
[19]. BOUDEN, C. Influence of glass curtain walls on the building thermal energy consumption under Tunisian climatic conditions: The case of administrative buildings. Renewable Energy, v. 32, n. 1, p. 141–156, jan. 2007.
[20]. CHVATAL, K. M. S.; CORVACHO, M. H.; MALDONADO, E. A. B. Analysis of envelope thermal behaviour through parametric studies. Building Simulation, n. Proceedings of Eighth International IBPSA Conference, p. 195–202, 2003.

[21]. GRYNNING, S. et al. Windows in the buildings of tomorrow: Energy losers or energy gainers? Energy and Buildings, v. 61, p. 185–192, jun. 2013.