Office Buildings Façades: The Relationship between Costs and Performance

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ABSTRACT: This paper analyzes the thermal, energetic and economical performance of the office buildings façades, built from 1980 to 2000, in São Paulo. It also shows comparative analysis of the different solutions including the construction costs for materials and labor, the air conditioning systems installation costs, and the electric power consumption costs, spent by the systems to remove the internal heat gains during a lifecycle of 25 years.

A geometrical model that represents the typical office buildings features and dimensions was used in the computer simulations. The software Energy Plus was the simulation tool. It gives many kinds of output data and results about many thermal features and heat gains from the façades. The simulations results were the databases for the conclusions about the thermal performance of each façade, for the calculation of the air conditioning systems installation costs, and the electric power consumption costs associated.

The integrated analysis of the construction, installation and operation costs based on the method created in this research provide a complete performance evaluation method for the next office buildings designs, for a sustainable design approach, with less energy consumption and improving users comfort levels.

Keywords: energy consumption, office buildings façades, associated costs.

1. INTRODUCTION

Since 1980, the number of office buildings built in São Paulo has been increasing so much, especially in some parts of the city, like business centers created beside the most important streets. It's possible to see such kind of evolution in terms of height, dimensions, structure and materials.

The façades have turned into an important way of marketing and self image of the companies. But, in many cases, the design solution is not appropriated for the climate. The use of single glass curtain walls is very common, but it causes the increasing of the internal loads and often it's necessary to keep the air conditioning systems working even during the winter. The energy consumption could be reduced if the façades were designed with external shadings and less glass areas.

So, this work aims to analyze the thermal, energetic and economical performance of the office buildings façades, built from 1980 to 2000, in São Paulo. It shows comparative analyses of the different solutions including the construction costs for materials and labor, the air conditioning systems installation costs, and the electric power consumption costs, spent by the systems to remove the internal heat gains during a lifecycle of 25 years.

The first part of the work is the surveying and identification of the façades of 81 office buildings. The selected features for the analyses are the window wall ratio (WWR), the glass type and the opaque materials.

Seven types of typical solutions were identified:

T1 - Façades with glass in almost 100% of the area, like glass curtain walls
T2 - Façades with some glass area and some opaque area made of brick walls covered in the outside face with stone plates.
T3 - Façades with some glass area and some opaque area made of brick walls covered in the outside face with aluminum plates.
T4 - Façades with some glass area and some opaque area made of premoulded concrete walls.
T5 - Façades with some glass area and some opaque area made of brick walls covered in the outside face with ceramics plates.
T6 - Façades with some glass area and some opaque area made of brick walls covered in the outside face with mortar and paint.
T7 - Double skin façades with external glass curtain walls, internal surfaces with some glass area, and a natural ventilated space between them, 0,80 m wide. This natural ventilation is created by the overheating of the internal air, which temperature is higher than the external one. So, the external air flows inside the interstice space through low openings and comes out by high ones.

In countries with hard winter time, double skin façades can be used as heating spaces by closing the openings and increasing internal heat gains.

2. THE FAÇADES CONSTRUCTION COSTS

The construction costs of the seven types of façades have included the costs for materials and

labor, considering the variation of the WWR, as 50%, 70% and 90%, with or without exterior solar shadings.

The analyses of the results show that:

- The cheapest one is the façade with WWR 50%, opaque area made of brick walls covered in the outside face with mortar and paint, without exterior solar shadings;
- The most expensive one is the double skin façade with WWR 90% in both glass walls;
- Façades with WWR less than 70% and the opaque area made of brick walls covered in the outside face with mortar and paint, ceramics plates or premoulded concrete walls, without exterior solar shadings are in the lower costs group. These types of façades with exterior solar shadings still have lower costs than façades with glass curtain walls;
- Façades with WWR more than 70% and the opaque area made of brick walls covered in the outside face with aluminum or stone plates, with exterior solar shadings are in the higher costs group.

3. COMPUTER SIMULATIONS

3.1 The Building Model

The geometric model used in this research's simulations was developed based on the characteristics of most of São Paulo office buildings designed between 1980 and 2000[1] as following:

- A square model with four equal zones and same areas;
- A core area with vertical circulations (stairs and elevators) and facilities systems such as HVAC, bathrooms and storage rooms;
- Floor area: 1225 m^2 (35 m x 35 m);
- Office area with 2,70 meters height (floor to ceiling).
- Internal loads:
  - People: 37 persons in each zone. Office activity.
  - Lighting: 12 W/m^2
  - Equipments: 45 W/m^2

These of internal loads are very usual in office buildings in São Paulo, and are results of some researches developed by School of Architecture and Urban Design of University of São Paulo.

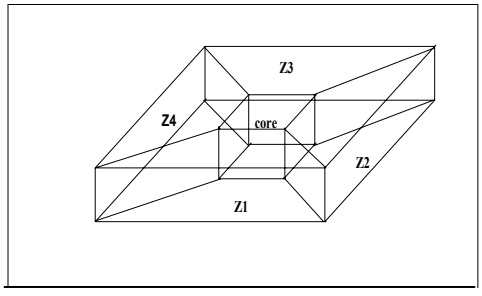

Figure 1 – The model

3.2 The Simulation Tool

Energy Plus is a building energy simulation program for modelling building heating, cooling, lighting, ventilating, and other energy flows.

While it is based on the most popular features and capabilities of BLAST and DOE-2, it includes many innovative simulation capabilities such as time steps of less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, and photovoltaic systems.

Energy Plus is a stand-alone simulation program without a 'user friendly' graphical interface; it reads input and writes output as text files.

3.3 Results

Comparing the types T1, T2, T3, T4, T5, and T6, with the same WWR value and the same external solar shading design, the internal loads removed by the air conditioning system are almost the same. For example: for WWR 90% solution with aluminium façades and without external solar shading, the amount is 204.598 kWh, and for WWR 90% solution with mortar and paint and without external solar shading the amount is 204.773 kWh.

This results show us that in terms of internal loads removed by the air conditioning system, the opaque façade materials have a few participation (Table 1). The glass surfaces (no-opaque) areas are responsible for the most internal loads as well the air conditioning energy consumption (Table 2).

Table 1 – K value - Thermal transmission coefficient

Façade Type	K-value ($W/m^2.°C$)
T1 – glass curtain walls	2,58
T2 - glass and stone plates.	2,71
T3 – aluminium	2,56
T4 - premoulded concrete walls	3,62
T5 - ceramics plates	2,24
T6 – mortar and paint	2,49
T7 - double skin	0,46

In the research, silver reflective glasses where used in façades without external solar shadings and uncoloured float glasses in façades with external solar shadings, both with thickness 0,008m.

Table 2 – g value

Glass Type	Solar transmission
Silver reflective glass	0,22
Uncoloured float glasses	0,71

In an anterior research, using the same model, the authors also compared the performance of the office buildings façades, but, without putting the internal loads among total heat gains. So, the results show comparative analyses between WWR values and the solar shadings influence. In that case, without internal loads took into consideration, the internal heat gains

can be reduced in almost 40% when façades with WWR 90% without external solar shadings and façades with WWR 50% with external solar shadings are compared.

But the internal loads are the great responsible for the internal heat gains. So the numbers come lower for the same analyses.

When any type of façade with WWR 90% without external solar shading and another one with WWR 50% with external shading are compared the reduction is around 14%.

For types T1 to T6 WWR 90%, 70% and 50%, when external solar shadings are used, the internal loads are reduced in 6% to 7%.

Reducing the WWR from 90% to 50%, in façades without external solar shading, the internal loads are reduced in 9%. Repeating this simulation in façades with external solar shading, the internal loads are reduced in 7%.

When a simple glass curtain wall (T1) is compared to a double skin façade (T7). For T7 type, the consumption is reduced in 23%. Windows can be opened to this natural ventilated space during the whole year, increasing internal heat loss. But the opaque internal surfaces have to be covered by some acoustics material in order to reduce sound transmission from one floor to the others.

4. AIR CONDITIONING SYSTEMS COSTS

4.1 Installation Costs

The total amount per of air conditioning systems Installation costs versus type of façades are very close among them. The range goes from US$ 163/sqm to US$ 182/sqm i.e., 10%.

Now a day, in Brazil, the average consumption by end-use in office buildings for air conditioning systems is about 30%. It was 50% in the 70s.

4.2 Operation Costs

The operation costs of the T1 to T6 façades are very similar. In office buildings the internal loads (artificial lighting, people and equipments) are very high, so, as a consequence, the façades heat gain as percentage numbers, are very similar, and much lower than the internal loads.

The use of external solar shadings can reduce about 3% or 4% of the costs, when façades with the same WWR are compared.

The operation costs of the solutions T1 to T6 with WWR 50% with external solar shadings are 7% lower than the solutions T1 to T6 with WWR 90% without external solar shadings

The solution T7 (double skin façades) has lower operation costs than the solutions T1 to T6. Comparing the best solution T7 (double skin façades) to the worse solution T1 (single glass curtain walls), the difference is about US$1.700/year/floor, or, the T7's energy consumption is 12% lower than T1's.

Considering that the energy consumption for the air conditioning systems is about 30% of the whole energy consumption of the office buildings in São Paulo, this difference means a reduction of 3% for total rate of the building. So, it's possible to say that instead of the very small savings for the companies' investments, it'd be very important to the economy of the nation, because, for each 30 efficient new buildings, the consumption of an entire one could be saved.

5. CONCLUSIONS

5.1 The total costs composition

The analyses of the total costs composition show that the construction costs have the lowest percentage values, that vary from 6% (WWR 50%, opaque area made of brick walls covered in the outside face with mortar and paint, without exterior solar shadings) to 21% (double skin façade with WWR 90% in both glass walls).

The air conditioning systems installations costs are very similar for the seven types of façades, and vary from 30% e 35% of the total costs.

The operation costs have the highest percentage values, that vary from 49% for the highest construction cost (double skin façade with WWR 90% in both glass walls) to 58% for the lowest construction costs (WWR 50% and the opaque area made of brick walls covered in the outside face with mortar and paint, ceramics plates or premoulded concrete walls, without exterior solar shadings).

Almost half of the investment has to be done by the constructor of the building, during the first one or two years, while the building has been done. The other half will be paid by the users, during the building lifecycle.

The results also show that it's important to consider all the related costs: construction, installation and operation of the air conditioning systems to have real total costs.

5.2 The building construction costs x operation costs

The analyses of the results show that designs with passive architecture features like external solar shadings or double skin façades can increase the construction costs of the façades. But, on the other hand, the air conditioning systems costs and the operation costs can be reduced.

For instance, if the sollution with double skin façades (T7) and the sollution with a simple glass curtain wall (T1) are compared, the conclusions are:

- Both façades look very similar;
- The construction cost of T7 is 23% higher than T1's;
- The thermal performance of T7 is better, so the operation cost is 22% lower and the installation cost is 10% lower than T1's;
- After 25 years, the total cost of T7 is 4% lower than T1's.

If façades with the same WWR, but with or without exterior solar shadings are compared, the conclusions are:

- They look very different;
- The construction costs of the façades with exterior solar shadings are higher than the façades without exterior solar shadings, from 15% to 25% depending on the WWR value;

- The thermal performance of the façades with exterior solar shadings are better, so the operation costs are 3% lower and the installation costs are 2% lower than the façades without exterior solar shadings';
- After 25 years, the total costs of the whole solutions are very similar; the differences are about 1%.

So, the higher investments made during the building construction can be paid back by the reduced investments during the building operation. In Brazil, the electric power is still not expensive, and the time of the return of investments in better architectural solutions is very long.

5.3 Total costs

Comparing the higher total cost value (simple glass curtain wall) with the lower total cost (WWR 50% and the opaque area made of brick walls covered in the outside face with mortar and paint, without exterior solar shadings), the difference is about 12%, that means US$ 77.000, for a 25 years period.

It's important to see that the solution with higher total cost is the worse solution in terms of thermal comfort and energy consumption.

5.4 The consequences for the environment

Nowadays, Brazil is an urban country. There are more than 183 million persons living in urban areas, about 81% of the whole population. These numbers are increasing year by year.

Brazil is the 10° electric power producing country, and the consumption increases about 4% by year, such as 16 TW each year.

The commercial and public buildings are responsible for 22% of the electric power consumption. So, the reduction of 3% of the consumption for the new buildings represents such an important thing for the sustainability of the nation.

The reduction of the buildings energy consumption must be controlled by specific laws, such as the experience developed since 1974 in many developed countries around the world.

It'd bring so many benefits for people who work in these kinds of places; because high thermal and energetic performance buildings also have much better comfort levels.

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