Heat Balance Analysis of an Office Building with Fully Glazed Façade in Tropical and Temperate Climates in Brazil

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Abstract
Even though insulating glass units (IGU) are widely used in Europe and North America, previous studies show that its use can increase the HVAC energy consumption in office buildings instead of improving thermal performance. This study aims to investigate the effect of IGU use in thermal behaviour of buildings in the Brazilian climate context. Heat balance analysis of an open-plan office floor was conducted, mainly focusing on heat flux through windows. The data were obtained by computer simulation in EnergyPlus. IGU use is compared with a non-insulated system. Results show that the IGU use avoids a beneficial heat dissipation throughout the window during the night, mainly in the southern region. Even in hot climates, non-insulated glass presents the potential to dissipate the thermal load during occupation time yet.

Key Innovations
- Heat balance analysis to investigate the effects of IGU use in open-plan office buildings located in temperate and tropical climates.

Practical Implications
Heat balance analysis carried out with outputs from EnergyPlus showed useful to understand the heat flow throughout the building envelope, mainly in an hourly basis.

Introduction
The appropriate choice of building envelope systems is a pivotal factor to maintain the indoor environmental quality and to maximize buildings energy efficiency, regardless of variations in external conditions. In this context, the concern about the glass choice is emphasized as long as the most direct and intense heat exchanges occur through this material due to its solar radiation openness and high thermal transmittance. Furthermore, the glass tends to cause a greenhouse effect in the indoor environment due to its transparency to short-wave radiation but opacity to long-wave from indoor surfaces. For this reason, the heat transmission by conduction is slower than the solar radiation admission.

Therefore, the glass choice shall be proper to the building operation and the local climate. Singh and Garg (2009) emphasize the connection between climate and energy-saving since the same window will not perform the same in distinct places. Nevertheless, the current corporative building architecture design bases on extensive glass panes all over the world. This fact increases the internal load even more and, consequently, the energy disease for cooling (Huang; Niu, and Chung, 2014).

In the Brazilian context, the insertion of an international architecture models occurs not only in the façade design but also in the constructive system, as the use Insulated Glass Unit (IGU) for example, usually in double panes. Increasing the thermal resistance of the window or façade is the main effect of this system, which reduces the heat flow by conduction through the building envelope (Huang, Niu, and Chung 2014a). In Europe and North America, IGU is used broadly as a strategy to improve buildings energy performance while providing thermal comfort for the occupants. However, this glazing system has been applied in Brazilian office buildings without a proper weather assessment (Besen and Westphal 2014).

Among the researches that analyze the thermal performance of IGU in different climate contexts, the main focus are the glass type and the number of layers. Among which can be cited Poirazis, Blomsterberg, and Wall (2008); Tzempelikos et al. (2010); Jaber and Ajib (2011); Gasparella et al. (2011); Wen (2012); Lee et al. (2013); Atzeri et al. (2016); Wen, Hiyama, and Koganei (2017); Berardi (2019); and Graiz and Al Azhari (2019). However, it is not usual to find analyses that compare the thermal performance among IGU and Single Glass Units (SGU).

The study of Poirazis, Blomsterberg, and Wall (2008), in Gothenburg, Sweden, indicated that the use of a low thermal transmittance window decreases the demand for heating without significantly influencing the cooling demand. However, they evaluated only alternatives with a high level of thermal insulation, i.e., barely IGU with one or two gas layers.

Among the cities investigated by Lee et al. (2013), Taipei and Shanghai show a climate classification Cfa (temperate; humid; hot summer), according to Köppen-Geiger, which can be found also in southern Brazil. For these cities, the best performing window systems were double-glazing, the least insulated among those tested.

Nevertheless, it is important to highlight the relation between proper glass choice and the local climate. Ideal properties and configuration of windows, such as window-to-wall-ratio (WWR) and optical properties of glass, may change according to the weather (Wen, Hiyama, and Koganei 2017).
While the double glass units are the standard windows model in rigorous winter localities, a study of Chow, Li, and Lin (2010) indicated the possibility that multiple glass layers are not recommended in warmer climates, unless if applying a mechanism to reduce the solar radiation admission. Moreover, Jaber and Ajib (2011) state the heating load is more influenced by the window size, whereas the type of window (single, double, or triple glass unit) further affects the cooling load. Tropical areas have less climatological conditions fluctuation throughout the year. Differently, countries in North America and Europe tend to have more rigorous winters and higher thermal amplitude between seasons.

Previous studies in Brazil have shown that IGU may not provide better performance than SGU (Andreis, Besen, and Westphal 2014; Westphal and Andreis 2016; Besen and Westphal 2014; Pinto and Westphal 2019). Besen and Westphal (2014) compared the energy performance and economic feasibility of different glass types (monolithic, laminated, and IGU) in a fully glazed office building for six Brazilian cities. The results indicated that the laminated glass tends to achieve better economic viability even when the use of IGU presented a lower consumption. IGU tends to yield a higher payback period due to their higher initial cost. Pinto and Westphal (2019) analyzed the impact of the IGU use on thermal energy performance of conditioned open-plan office buildings for a significant range of climates found in Brazil. Based on the results of cooling consumption, the authors state that the IGU use is not justified in southern Brazil (temperate climate) for this type of building. Conversely, results for tropical climates showed similar performance among IGU and Single-pane Laminated Glass Units (SGUs), with a slight advantage for IGU models. These results disagree with common sense that the IGU is a strategy to improve energy efficiency, especially in extreme cold or hot climates. These studies showed the need to understand in more detail how the heat transfer occurs throughout the façade along the day. Heat balance analyses consider the heat exchanges between room surfaces, which are influenced by the outdoor and indoor air conditions. These researches allow to verify the role of each building component in the thermal load and to recognize the sources of heat gains and loss (Didoné, Wagner, and Pereira 2014). Besides that, it allows assessing the influence of construction parameters shift in the indoor heat flow.

The present study aims to investigate when the IGU can improve positively the building thermal insulation concerning outdoor climate and when it would be negative. For this purpose, heat balance analyses were carried out for a conditioned office building in the Brazilian climate context, mainly focus on the heat flux through windows. These analyses were performed based on heat flux obtained from building simulation in EnergyPlus for two Brazilian cities with different climate conditions, Curitiba and Boa Vista.

### Methods

Two Brazilian cities with different climate conditions were selected for heat balance analyses. Curitiba, temperate climate city in southern Brazil, is among the Brazilian capitals with lower annual average global solar radiation, from 4.55 to 4.90 kWh/m², and also lowest annual average outdoor air temperature (17.2 °C). On the other hand, Boa Vista, a tropical city in the North, is among the capitals with higher global solar radiation, from 5.25 to 5.60 kWh/m. Boa Vista presents also high average outdoor temperature and constant solar radiation intensity (Pereira et al. 2006; Pinto and Westphal 2017). The selection of windows specifications for each city was based on the results obtained by Pinto and Westphal (2019). The authors carried simulations on EnergyPlus out for nine cities and different façades configurations were tested varying SHGC (Solar Heat Gain Coefficient), WWR, and type of window. The SHGC varied from 0.28 to 0.57, and the WWR from 30% to 60%.

Among the results that previous research, a pair of models both with the same SHGC and WWR but one model with IGU and the other with SGU, were selected for Curitiba and Boa Vista. The choice consists in the pair with the higher difference of cooling consumption between types of glass for each city. For Curitiba, the model with SHGC 0.52 and WWR 60% was selected, and for Boa Vista, the model with SHGC 0.28 and WWR 60%. Therefore, heat balance analyses were conducted to observe the thermal behaviour during a summer and a winter day for the four chosen models.

#### Building Modeling

A typical open-plan configuration floor of an office building, based on the research of Lam and Hui (1996) and applied in Pinto and Westphal (2019), was analyzed (Figure 1). It was virtually positioned on the tenth-floor height (i.e., 30 meters high). Ceiling and floor surfaces were set as adiabatic partitions, considering adjacent thermal zone at the same temperature conditions. The floor was divided into nine thermal zones: four peripherals, four internal, and a central core. All zones are artificially conditioned, except the core zone.

![Figure 1: Schematic plan and thermal zoning of the typical floor (unit: m)](https://example.com/figure1.jpg)
Table 1 shows the thermal transmittance (U-value) and solar absorptance of opaque envelope compositions. The model has exterior walls covered (spandrel glasses) with the same SGU, used in the windows. This configuration has been set on EnergyPlus as a transparent thermal insulation material through the “SurfaceControl: MovableInsulation” input object, which provides thermal insulation (due to air layer between the glass and exterior wall) without drastically decreasing the solar energy transmittance.

**Table 1: Thermal properties of materials**

<table>
<thead>
<tr>
<th>Composition</th>
<th>U-Value (W/m²·K)</th>
<th>Solar Absor.</th>
<th>Heat Capacity (kJ/m²·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterional Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasterboard (12.5mm) +</td>
<td>0.77</td>
<td>0.297</td>
<td>24.31</td>
</tr>
<tr>
<td>Glass wool (50mm) +</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement board (10mm) +</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasterboard (15mm) + Glass wool (50mm) + Plasterboard (15mm)</td>
<td>0.69</td>
<td>0.297</td>
<td>25.55</td>
</tr>
<tr>
<td>Ceiling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasterboard (15mm) + Mortar (25mm) + Concrete slab (200mm) + Mortar (25mm) + Ceramic floor (7.5mm)</td>
<td>1.40</td>
<td>0.297</td>
<td>11.03</td>
</tr>
</tbody>
</table>

Table 2 presents a summary of optical and thermal properties of glass types (ABNT, 2008). Equipment load density was set 21.5W/m², occupancy density based in Brazilian standard for HVAC and occupancy of 7.7m² per person. Metabolic rate for each person was established in 126W/person, as an office sedentary activity according to Annex B of ISO 7730: 2005 (ISO, 2005). Figure 2 shows the schedules of building use and occupancy. The office is not occupied during weekends. Lighting and equipment follow the occupancy pattern, with five percent of loads remaining in operation during off occupancy time.

**Figure 2: Workweek schedule occupancy**

The building is artificially conditioned by PTHP (Packaged Terminal Heat Pumps). The HVAC system key features, which was programmed to be available from 7 am to 9 pm on weekdays, according to cooling and heating needs. As there is no occupancy in the building during weekends, the air conditioning is not activated in that period. Natural ventilation was not modeled, and the mechanical ventilation of the PTHP system provides the indoor air recirculation plus the outdoor fresh airflow rate.

**Table 2: HVAC system characteristics**

<table>
<thead>
<tr>
<th>System</th>
<th>PTHP (Packaged Terminal Heat Pump)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Rated COP</td>
<td>3.0 W/W</td>
</tr>
<tr>
<td>Capacity</td>
<td>Auto sized by EnergyPlus</td>
</tr>
<tr>
<td>Outdoor air rate</td>
<td>0.0075 m³/s per person</td>
</tr>
<tr>
<td>Setpoints</td>
<td>Heating: 20°C - Cooling: 24°C</td>
</tr>
<tr>
<td>Infiltration rate</td>
<td>0.3 air changes per hour</td>
</tr>
</tbody>
</table>

**Heat Balance Analysis**

The heat balance analyses were conducted for the four peripheral zones, each one representing one solar orientation. Hourly data of heat flux by convection on indoor surfaces (walls, ceiling, floor, and windows), by indoor heat load (people, equipment, and light system), and by air infiltration from outside were obtained by computer simulation on EnergyPlus. The thermal load requested by the HVAC was also verified. It is relevant to highlight that the portion assigns as window contribution only count the heat transmitted to

**Table 3: Summary of optical and thermal properties of glass types**

<table>
<thead>
<tr>
<th>Local</th>
<th>Thickness [mm]</th>
<th>U value [W/m²·K]</th>
<th>SHGC</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boa Vista</td>
<td>Manufacturing Process</td>
<td>Laminated clear</td>
<td>5.63</td>
<td>Laminated + air gap + monolithic</td>
</tr>
<tr>
<td></td>
<td>U value [W/m²·K]</td>
<td>0.28</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>Curitiba</td>
<td>Manufacturing Process</td>
<td>Laminated clear</td>
<td>5.6</td>
<td>Laminated + air gap + monolithic</td>
</tr>
<tr>
<td></td>
<td>U value [W/m²·K]</td>
<td>0.52</td>
<td>0.49</td>
<td></td>
</tr>
</tbody>
</table>

The windows go through the full length of the floor, covering 60% of the façade. The types of glass were selected from products sets available in the Brazilian market. Table 3 shows a summary of optical and thermal properties of laminated single-pane glass units and insulated glass units for each city, but in EnergyPlus software, the simulation has considered spectral average properties regarding light and heat transmittance and reflectance for each pane of glass (two panes in case of IGU) under analysis. Thermal properties for IGUs presented in Table 3 were calculated in the WINDOW 7.4 software (LBRLN, 2016). All fenestration received roller blinds with medium reflectance (50%) and low transmittance (10%) as shading devices. The model was programmed to close the blinds when the solar radiation incident on windows exceeds 250 W/m². Internal loads densities were defined for offices with high occupancy density based in Brazilian standard for HVAC sizing and design (ABNT, 2008). Equipment load density was set in 21.5W/m², lighting capacity density in 16W/m², and occupancy of 7.7m² per person. Metabolic rate for each person was established in 126W/person, as an office sedentary activity according to Annex B of ISO 7730: 2005 (ISO, 2005). Figure 2 shows the schedules of building use and occupancy. The office is not occupied during weekends. Lighting and equipment follow the occupancy pattern, with five percent of loads remaining in operation during off occupancy time.
the indoor environment - or absorbed by the glass – by convection. It means this output contemplates the ratio of radiation absorbed by the glass plus the heat gain by convection in its outside surface. However, evaluation of the solar radiation impact on the indoor heat balance requests the short-wave radiation transmitted directly through the glass is considered. For this reason, the solar distribution in these models was set as Full Exterior. It assumes all direct solar radiation that crosses the window is drive to the floor and absorbed according to the floor absorptance. The heat remain is distributed uniformly in the other internal surfaces.

One week of summer (from February 11th to 17th) and one week of winter (from August 12nd to 18th) were chosen for the analyses. Due to Brazil's wide geographical distribution, especially latitudinal, it is recognized that Boa Vista does not present summer and winter seasons, but periods of drought and rainy periods. However, the Southern Hemisphere season pattern was used as a nomenclature to characterize the selected periods. Same dates were considered for both cities to evaluate also the angle variation of solar radiation incidence.

The analyses were divided into two steps. First, the heat gains and losses were summed for each representative week. Then, the hourly heat flux of a single day has been assessed. The heat exchanges were also analysed against outdoor and indoor air temperature conditions.

Results and Discussion

Figure 3 and Figure 4 show the heat balance throughout one summer and one winter week of Boa Vista and Curitiba, respectively. The peripheral zones of four solar orientations are analysed. The graphics also compare the use of IGU and SGU. The internal gains tend to represent a higher contribution to the HVAC cooling demand when related to other heat gain sources.

The thermal behaviour of this building model in Boa Vista tends to maintain the same characteristics in the two representative weeks and all solar orientations (Figure 3). It happens due to the narrow fluctuation of monthly average air temperature throughout the year in this city. Besides that, the difference in annual average solar radiation incidence between solar orientations is reduced. On the other hand, Curitiba (Figure 4) shows a significant difference in thermal behaviour among summer and winter, and slightly variations between solar orientations. Figure 5 shows the outdoor air temperature fluctuation throughout the summer and winter representative weeks. Curitiba presents a beneficial potential of indoor heat dissipation through windows and infiltration even during summer. In contrast, the heat balance for Boa Vista demonstrated only heat gain through these sources in both periods. This disparity occurs due to a higher daily temperature range in Curitiba and temperatures close to 20°C during the night. The IGU presents a lower potential to act as passive cooling by heat dissipation through the window due to its higher thermal resistance. It is relevant to highlight that the indoor cooling demand during the occupied period occurred all year round in these models.

Both glass types showed similar results in the annual analysis for Boa Vista. The IGU blocked the heat gain from conduction and convection through the window.
between 2.1% and 8.7% more than the SGU. The use of IGU in the tropical climate also reduces the indoor cooling demand from 2.7% to 6.5%.

In contrast, the difference between both window systems and solar orientation is significant in Curitiba. The IGU model shows higher heat gain in both periods. During summer, the IGU shows up to 3.5 times higher heat gain through the windows in the south zone. There, the heat balance of the IGU model resulted in lower heat loss, and the SGU allowed higher heat dissipation. During winter, this disparity is emphasized. The SGU model presents from 110% to 510% more potential for heat dissipation through the window. As a consequence, the SGU model reports from 17.7% to 37.7% lower cooling demand.

The hourly heat balance on Wednesdays of the summer and winter weeks are analysed in order to enlighten these results. Figure 6, Figure 7, Figure 8, and Figure 9 report the heat balance of the zone oriented to the east in Boa Vista models. In terms of hourly heat exchanges through the window, the results do not present meaningful differences among IGU and SGUL use (up to 0.50kWh).

During the day, the IGU tends to block the heat transfer more than SGUL. On the other hand, during the night, when there is no occupation and the gap between outdoor and indoor temperatures decreases, the SGU allows more efficient heat dissipation. Nevertheless, the contrast in the results of both glazing types is from 0.01 to 0.48 kWh. For this reason, it is not possible to consider the difference significant in the uses of IGU or SGU in tropical climates as Boa Vista. The results for west, south, and north orientation show the same pattern in both summer and winter periods.

Similar thermal behavior is also verified during the summer day in Curitiba, as exemplified for the north zone in Figure 10 and Figure 11. However, in this case the SGU allows higher heat loss during the day, except during the solar radiation peak in the façades east (9-12h), north (11-16h), and west (14-17h). As well as occurred in Boa Vista, the numerical difference was not significant.

In contrast, the thermal behavior presented a meaningful difference between glazing types during the winter day (Figure 12 and Figure 13). The SGU resulted in lower heat gain over the peak of solar radiation incidence in each façade for all orientations. The SGU glass also increases heat loss during the occupied period when the hourly balance is analyzed. This difference reaches 0.73kWh per hour. The dissipation becomes even more efficient during

![Figure 5: Hourly average outdoor air temperature fluctuation of summer and winter representative weeks](https://doi.org/10.26868/25222708.2021.30444)
The night when this gap achieves 26,80kWh (94% higher), considering the sum of whole floor (the four orientations).

The cooling demand occurred all over the occupation period, even when the hourly outdoor air temperature was lower than the heating setpoint. The gap between indoor and outdoor air temperature reached 19,8 °C. The cooling demand increases due to the high internal load and the significant radiation heat gain through the façade lead. The window oriented to the South allows heat loss through the façade all day long because of the large difference between indoor and outdoor temperature associated with a low incidence of solar radiation (Figure 14 and Figure 15). The annual average solar radiation incidence in this façade in Curitiba tends to be about 50% of the other orientations (Figure 16), which substantially decreases the heat flux through the window.

The large gap between indoor and outdoor temperatures occurs in the four solar orientations. In this context, the higher thermal insulation of the IGU system hinders the heat dissipation through the windows when the heat loss
can contribute to minimizing the air-cooling demand and, therefore, the electricity consumption.

The heat balance analysis ratifies the diagnostic found in previous research for this building typology, as in Pinto and Westphal (2019). Even in hot climates, SGUs present a better potential to dissipate the indoor thermal load during occupied times if wide daily range in outdoor temperature is detected. During the occupied period, the IGU mitigates the heat gain through the windows when the outdoor temperature tends to be higher than indoor. However, the use of IGU reduces the capability of nocturnal heat dissipation due to the high thermal insulation of this system. This heat loss would be advantageous as it would decrease the thermal load for HVAC at the beginning of the next day or week.

The present study does not analyze the thermal behavior considering other WWR percentages. However, some aspects can be envisaged based on the HVAC consumption results of Pinto and Westphal (2019). The models selected for this study were the pairs that presented the highest difference in cooling consumption between IGU and SGU, use. Presumably, the lower the WWR lower the contrast in thermal behavior between both glass systems because the lower is the window influence in the building heat exchanges. Conversely, when the WWR is higher than 60%, possibly the nocturnal heat dissipation potential increases by using IGU, and this system present a more beneficial thermal balance than SGU. However, more studies would be necessary.

**Conclusion**

This research focuses on the effect of insulated glass units (IGU) in the heat balance of an open-plane office building floor artificially conditioned by an HVAC system. Two Brazilian cities were analyzed: Curitiba (temperate climate) and Boa Vista (tropical climate). The heat balance data were obtained by computer simulation in EnergyPlus software.

In hot climates, the IGU mitigates the heat gain through the windows when the outdoor temperature tends to be higher than indoor. However, this system reduces the heat dissipation potential of internal load during the night and non-occupied periods, which increases the HVAC demand at the beginning of the workday.

Although southern Brazil can register low temperatures during winter, the climate stills mild compared to a global scale, such as in the United States, Canada, and Europe. The use of IGU is a strategy to reduce heating energy consumption in these countries. However, the increase of glass façade thermal insulation can avoid the heat dissipation of internal sources in milder climates.

Solar radiation is undoubtedly one of the most effective heat gain sources from the outdoor environment in buildings with fully glazed facades in Brazil. Nevertheless, it will not be one of the most relevant climatic factors in the IGU use viability concerning thermal performance. Since thermal insulation is the most significant feature of this type of glass, the difference between outdoor and indoor air temperature is a key factor in the IGU chose as a façade solution.

It is necessary to highlight that these conclusions only apply to an office building model as described here, which
open-plan office spaces, high internal loads density, a PTHP air conditioning system, and no exterior shading devices.

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References


