EVALUATES OF INFLUENCE OF THE SPECIFICATION OF THE GLASS OF WINDOW IN THE ENERGY CONSUMPTION OF THE CONSTRUCTIONS IN BRAZIL.

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Summary
The study evaluates the influence of the specification of the glass of window in the energy consumption of the constructions. It uses software RESFEN 5.0, developed for Lawrence Berkeley National Laboratory of California for calculation of thermal load and costs of conditioning of a construction related to the properties of the window. It was simulated a typical construction with one floor of 100 m² in the city of Belo Horizonte and São Paulo. The evaluated glasses had been: Float 4 mm clear (reference), Float 3 mm clear, Float 6 mm clear, Float 4 mm green, Float 4 mm grey, Laminated 8.4mm clear, double glass (4 mm + 6 mm of air + 4 mm) clear. The calculations had been made for the orientation west, of bigger incidence of solar energy. They had been simulated also, the orientation north, east and south for the window with the reference glass. The variation of the thickness of the glass showed resulted modest in the energy efficiency of the window, similar in the two cities. The color of the glass produced resulted significant in the improvement of the energy efficiency of the window, also similar in both the cities. The glass systems (laminated and double glass) had produced a medium results in the energy efficiency of the window, being that, in São Paulo, the double glass had better performance of what in Belo Horizonte. The orientation of the windows showed great influence in the building energy consumption related to the window. However, the orientation east presented different results in the two cities, with small reduction in Belo Horizonte and great reduction in São Paulo.

1. Introduction
Great part of the energy consumed in the constructions is used for thermal conditioning and illumination. The solar radiation is the main agent to determine the characteristic of thermal and illumination performance of the building. It is energy that brings beyond energy in the form of visible light, energy in the form of heat for the building; therefore she must be used carefully. Design, the architectural details and the materials used in the building, have direct influence in how the building relates, appropriates and controls the solar radiation.

2. Simulation tool - RESFEN 5.0
Program RESFEN is software, developed for Lawrence Berkeley National Laboratory of California (LBNL), United States, as a tool to assist in the choice of the window with better energy efficiency and better cost for determined residential application (figure 01). It calculates the used energy for conditioning, heating and refrigeration and associates the cost and peaks of consumption, of a determined window. The RESFEN uses DOE 2.1E (LBL 1980, Winkelmann et al. 1993) as tool of energetic balance calculation.

The RESFEN uses a custom version of the DOE-2.1E configured in dynamic link libraries (DLL) for operation in PC platforms. The DOE-2 is a term-energy program of simulation of constructions, also developed for the LBNL, known and widely used. As the DOE-2 reproduces the typical constructions characteristics of its native country, the simulation process must have a critical analysis in relation a variable adopted automatically by program. The DOE-2 did not have its basic algorithms modified. The results calculated for identical situations, are equal in the RESFEN and in DOE-2.1E.

In version 5.0, the RESFEN allows that if it defines a type of residence (one or two floor, frame or masonry), geographic localization (BIN archives), details of the core and shell of the construction (walls, floor and ceilings), type of HVAC systems (gas, electric, heat pump), cost of electricity and gas, orientation and thermal properties of the window in study. The thermal data of the window required are the U-value, SHGC and air leakage. It can be defined the solar gain reduction. The possibility of use a climatic BIN archives, together with the definition of the properties of the core, shell and windows,
allows the study to use the RESFEN in other countries. Version 5.0 have library for China and Chile, beyond U.S.A. and Canada.

Figure 01 – RESFEN main screen.

Based in the supplied data, RESFEN generates a BDL archive (Building Description Language) for DOE-2, and then, processes the archive as an entrance module (DOEBDL). After that the module is simulated, using the defined climatic archive. The simulation generated an archive with the consumption and annual cost of the construction for heating and refrigeration, the peak demands, and how much of this consumed energy can be attributed for the window. Figure 02 presents an organization chart of the calculation method.

Figure 02 - Organization chart of the calculation method.
3. Data and parameters

The RESFEN was configured for the locality of Belo Horizonte and São Paulo. The entrance data in program are presented in table 01.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Belo Horizonte</th>
<th>São Paulo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area.</td>
<td>100 m² (inside).</td>
<td>100 m² (inside).</td>
</tr>
<tr>
<td>House type.</td>
<td>Existing, one floor.</td>
<td>Existing, one floor.</td>
</tr>
<tr>
<td>Thermal values – Core and shell.</td>
<td>Basement: R0slab (Uvalue=0.438 W/m²K)</td>
<td>Basement: R0slab (Uvalue=0.438 W/m²K)</td>
</tr>
<tr>
<td></td>
<td>Floor: R11flr (Uvalue=0.416 W/m²K)</td>
<td>Floor: R11flr (Uvalue=0.416 W/m²K)</td>
</tr>
<tr>
<td></td>
<td>Walls : R7wall (Uvalue=0.594 W/m²K)</td>
<td>Walls : R7wall (Uvalue=0.594 W/m²K)</td>
</tr>
<tr>
<td></td>
<td>Roof: R11ceil (Uvalue=0.468 W/m²K)</td>
<td>Roof: R11ceil (Uvalue=0.468 W/m²K)</td>
</tr>
<tr>
<td>House perimeter.</td>
<td>40.5 meter – RESFEN standard: (floor area/14) + 56 , in feet.</td>
<td>40.5 meter – RESFEN standard: (floor area/14) + 56 , in feet.</td>
</tr>
<tr>
<td>Walls height.</td>
<td>2.44 meter – RESFEN standard.</td>
<td>2.44 meter – RESFEN standard.</td>
</tr>
<tr>
<td>Roof weight.</td>
<td>5.06 meter – RESFEN standard: 50% bigger dimension of the house.)</td>
<td>5.06 meter – RESFEN standard: 50% bigger dimension of the house.)</td>
</tr>
<tr>
<td>Infiltration</td>
<td>ELA=1.00 ft²(0.70 ACH)</td>
<td>ELA=1.00 ft²(0.70 ACH)</td>
</tr>
<tr>
<td>Structural mass</td>
<td>17.08 Kg/m² of floor area (RESFEN standard = 3.5 lb/ft²).</td>
<td>17.08 Kg/m² of floor area (RESFEN standard = 3.5 lb/ft²).</td>
</tr>
<tr>
<td>Internal Mass Furniture.</td>
<td>39.06 Kg/m² of floor area. (RESFEN standard = 8 lb/ft²).</td>
<td>39.06 Kg/m² of floor area. (RESFEN standard = 8 lb/ft²).</td>
</tr>
<tr>
<td>Window.</td>
<td>100 cm (weight) x 120 cm (height). Frame: Aluminium, single. Glass: as table 02. No solar gain reduction. Air leakage: 1.0 l/s-m².</td>
<td>100 cm (weight) x 120 cm (height). Frame: Aluminium, single. Glass: as table 02. No solar gain reduction. Air leakage: 1.0 l/s-m².</td>
</tr>
<tr>
<td>HVAC system</td>
<td>Electric heat pump</td>
<td>Electric heat pump</td>
</tr>
<tr>
<td>HVAC efficiency</td>
<td>AFUE = 0.70 A/C SEER = 8.0 (RESFEN standard)</td>
<td>AFUE = 0.70 A/C SEER = 8.0 (RESFEN standard)</td>
</tr>
<tr>
<td>Internal loads - (kBtu/day)</td>
<td>Sensible heat: 43,033 Btu/day + 8,42 Btu/ft² of floor area (illumination) Latent heat: 12,2 kBtu/day. (RESFEN standard)</td>
<td>Sensible heat: 43,033 Btu/day + 8,42 Btu/ft² of floor area (illumination) Latent heat: 12,2 kBtu/day. (RESFEN standard)</td>
</tr>
<tr>
<td>Natural ventilation.</td>
<td>By Enthalpic-Sherman-Grimsrud (25.55 °C / 22.22 °C – 4 day).</td>
<td>By Enthalpic-Sherman-Grimsrud (25.55 °C / 22.22 °C – 4 day).</td>
</tr>
<tr>
<td>Weather data</td>
<td>Bhrea95.BIN (LabEEE)</td>
<td>SaoPauloTRY1954_06.BIN (LabEEE)</td>
</tr>
</tbody>
</table>

The window was defined with simple aluminium frame, with dimension 1.0 x 1.2 meters each, and total area of twelve meters². The program allows only 12% of area of window in relation to the floor area. Diverse windows had been create, varying the glass through the determination of U-value and SHGC. Glasses with diverse thicknesses, diverse colors, lamination systems and double glass had been studied.

The U-value and SHGC of each glass had been gotten in the program Pilkington Spectrum V01.03.07 (figure 03), that it calculates the thermal and optics properties of glasses and its combinations, manufactured by Pilkington.
The properties are calculated by European Norm EN673 of U-value calculation and EN410 of solar and ótic performance of glasses. The bands of wave length considered are:

- UV Transmission  - 280-380 nm.
- Visible Transmission  - 380-780 nm.
- Solar Energy Transmission - 300-2500 nm.

The values of glass properties considered in Pilkington Spectrum calculation are:

- Thermal Resistivity     - $R = 1.0 \text{ mK/W}$.
- Corrected emissivity for uncoated float glass  - $e = 0.837$.
- Temperature difference inside/outside   - $dT = 150\text{K}$.
- Exterior heat transfer coefficient   - $he = 23.0 \text{ W/m}^2\text{K}$
- Interior heat transfer coefficient    - $he = 8.0 \text{ W/m}^2\text{K}$

The U-value is calculated in glass centre. The frame effect was not incluse in the calculation. The Pilkington Spectrum program was used because its have glass data equal of glasses that was manufactured in Brazil by Pilkington. The reference window uses float glass clear 4 mm.

The electricity cost in Belo Horizonte was defined R$ 0.664 \text{ kWh}$, having as reference the value of 100kW residential count, inclued taxes. The electricity cost in São Paulo was defined R$ 0.340 \text{ kWh}$, having as reference the value of 100kW residential count, inclued taxes.

To study the thickness influence, the colour influence and the glass system influence, in the energy consumption of building, each window was simulated with orientation west, that have a bigger thermal profit for the solar radiation.

The reference window was shaped in the north, east and south orientation, to evaluate the orientation influence in the energy consumption of building.

The studied glasses and the summary of its technician data, gotten in the Pilkington Glazing Calculator program, are shown in table 02.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{VIDRO} & \textbf{U-value (W/m²K)} & \textbf{SHGC} \\
\hline
Float Clear 4 mm. & 5.8 & 0.85 \\
Float Clear 3 mm. & 5.83 & 0.86 \\
Float Clear 6 mm. & 5.73 & 0.82 \\
Float Green 4 mm. & 5.8 & 0.66 \\
Float Grey 4 mm. & 5.8 & 0.67 \\
Laminated glass clear 8,4mm. & 5.7 & 0.77 \\
Doble glass 4 mm + 6 mm air + 4 mm – clear. & 3.3 & 0.76 \\
\hline
\end{tabular}
\caption{Glass technician data.}
\end{table}
4. Results

The summary of the results gotten for Belo Horizonte is shown in table 03.

<table>
<thead>
<tr>
<th>GLASS</th>
<th>ANNUAL COST DUE TO THE WINDOW (R$)</th>
<th>TOTAL ANNUAL COST (R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float clear 4 mm - West.</td>
<td>1725,23</td>
<td>2941,77</td>
</tr>
<tr>
<td>Float clear 3 mm - West.</td>
<td>1745,79</td>
<td>2962,58</td>
</tr>
<tr>
<td>Float clear 6 mm – West.</td>
<td>1649,99</td>
<td>2866,76</td>
</tr>
<tr>
<td>Float green 4 mm – West.</td>
<td>1253,99</td>
<td>2470,33</td>
</tr>
<tr>
<td>Float grey 4 mm – West.</td>
<td>1276,08</td>
<td>2492,45</td>
</tr>
<tr>
<td>Laminated clear 8,4mm – West.</td>
<td>1525,74</td>
<td>2741,81</td>
</tr>
<tr>
<td>Doble 4+6+4 mm clear – West.</td>
<td>1569,48</td>
<td>2786,45</td>
</tr>
<tr>
<td>Float clear 4 mm – North.</td>
<td>1175,91</td>
<td>2422,09</td>
</tr>
<tr>
<td>Float clear 4 mm – East.</td>
<td>1640,58</td>
<td>2906,59</td>
</tr>
<tr>
<td>Float clear 4 mm - South.</td>
<td>736,36</td>
<td>2087,88</td>
</tr>
</tbody>
</table>

The summary of the results gotten for São Paulo is shown in table 04.

<table>
<thead>
<tr>
<th>GLASS</th>
<th>ANNUAL COST DUE TO THE WINDOW (R$)</th>
<th>TOTAL ANNUAL COST (R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float clear 4 mm - West.</td>
<td>551,16</td>
<td>807,85</td>
</tr>
<tr>
<td>Float clear 3 mm - West.</td>
<td>559,17</td>
<td>815,83</td>
</tr>
<tr>
<td>Float clear 6 mm – West.</td>
<td>524,28</td>
<td>781,19</td>
</tr>
<tr>
<td>Float green 4 mm – West.</td>
<td>402,69</td>
<td>660,16</td>
</tr>
<tr>
<td>Float grey 4 mm – West.</td>
<td>409,20</td>
<td>666,53</td>
</tr>
<tr>
<td>Laminated clear 8,4mm – West.</td>
<td>483,03</td>
<td>739,99</td>
</tr>
<tr>
<td>Doble 4+6+4 mm clear – West.</td>
<td>480,45</td>
<td>736,55</td>
</tr>
<tr>
<td>Float clear 4 mm – North.</td>
<td>420,20</td>
<td>670,24</td>
</tr>
<tr>
<td>Float clear 4 mm – East.</td>
<td>393,82</td>
<td>638,21</td>
</tr>
<tr>
<td>Float clear 4 mm - South.</td>
<td>228,30</td>
<td>484,03</td>
</tr>
</tbody>
</table>

5. Analysis of the Results

The Belo Horizonte annual cost of conditioning due to the window, varying the glass, is showed in graph 01.

Cost due to the window

- Float clear 4mm
- Float clear 3mm
- Float clear 6mm
- Float green 4mm
- Float grey 4mm
- Laminated clear 8,4mm
- Doble 4mm+6mm+ 4mm

Clear glass 3 mm showed a annual cost of conditioning due to the window, R$ 20,56 or 1,19% greater
than the reference glass 4 mm.

Clear glass 6 mm showed annual cost of conditioning due to the window, R$ 75,24 or 4.36% lower than the reference glass 4 mm.

Color of the glass:

Green glass 4 mm showed annual cost of conditioning due to the window, R$ 471,24 or 27.31% lower than the reference glass 4 mm.

Grey glass 4 mm showed annual cost of conditioning due to the window, R$ 449,15 or 26.03% lower than the reference glass 4 mm.

Glass systems:

The laminated glass 8,4mm showed annual cost of conditioning due to the window, R$ 199,49 or 11.56% lower than the reference glass 4 mm.

Doble glass 4 mm + 6 mm + 4 mm showed cost of conditioning due to the window, R$ 155,75 or 9.03% lower than the reference glass 4 mm.

Window orientation:

The Belo Horizonte annual cost of conditioning by the window, varying the orientation, is showed in graph 02.

Graph 02 – Belo Horizonte, window orientation.

- The orientation north presented annual cost of conditioning due to the window, R$ 549,32 or 31.84% lower than the reference glass 4 mm.
- The orientation east presented annual cost of conditioning due to the window, R$ 84,65 or 4.91% lower than the reference glass 4 mm.
- The orientation south presented annual cost of conditioning due to the window, R$ 549,32 or 31.84% lower than the reference glass 4 mm.

The São Paulo annual cost of conditioning by the window, varying the glass, is showed in graph 03.

Graph 03 – São Paulo, glass variation.

- Float clear 4mm.
- Float clear 3mm.
- Float clear 6mm.
- Float green 4mm.
- Float grey 4mm.
- Laminated clear 8,4mm.
- Doble 4mm+6mm+ 4mm
Thickness:
Clear glass 3 mm showed an annual cost of conditioning due to the window, R$ 8,01 or 1.45% greater than the reference glass 4 mm.
Clear glass 6 mm showed annual cost of conditioning due to the window, R$ 26,88 or 4.87% lower than the reference glass 4 mm.

Color of the glass:
Green glass 4 mm showed annual cost of conditioning due to the window, R$ 148,47 or 26.93% lower than the reference glass 4 mm.
Grey glass 4 mm showed annual cost of conditioning due to the window, R$ 141,96 or 25.75% lower than the reference glass 4 mm.

Glass systems:
The laminated glass 8.4mm showed annual cost of conditioning due to the window, R$ 68,1 or 12.36% lower than the reference glass 4 mm.
Doble glass 4 mm + 6 mm + 4 mm showed cost of conditioning due to the window, R$ 70,71 or 12.83% lower than the reference glass 4 mm.

Window orientation:
The São Paulo annual cost of conditioning by the window, varying the orientation, is showed in graph 04.

Graph 04 – São Paulo, window orientation.
The orientation north presented annual cost of conditioning due to the window, R$ 130,96 or 23.76% lower than the reference glass 4 mm.
The orientation east presented annual cost of conditioning due to the window, R$ 157,34 or 28.54% lower than the reference glass 4 mm.
The orientation south presented annual cost of conditioning due to the window, R$ 322,86 or 58.58% lower than the reference glass 4 mm.

6. CONCLUSIONS
The thickness variation made a modest resulted in the energy efficiency of the window, in Belo Horizonte and São Paulo. An increase of 50% in glass thickness did 4.5% reduce cost of conditioning by the window.

The alteration of the glass color made a significant results in the energy efficiency of the window, in Belo Horizonte and São Paulo. A Reduction of 27% for the green glass was gotten. However the influence of the opacity in the natural illumination must be analyzed and eventual increases of energy consumption for natural illumination.

The glass systems made a medium results in the energy efficiency of the window, in Belo Horizonte and São Paulo. In Belo Horizonte, the laminated glass, with presence of another material (PVB-polymer) in the interior of the glass maded a reduction of 11.56%, superior than the doble glass (9.03% reduction), that it possess air layer with 6 mm in the interior. In São Paulo, city of more cold climate, the doble glass had better performance, with reduction of 12.83%, superior than the laminate reduction (12.36%). The most cold climate, and the influence of the glass isolation, can explains the result.

The windows orientation made a great influence in the energy consumption by the window. The south orientation showed reduction of 57.32% in the cost by the window for building conditioning in
Belo Horizonte. In São Paulo, reduction of 58.58% for south orientation was observed. The results had shown that the orientation east of the window cost different costs in Belo Horizonte and São Paulo. In Belo Horizonte, the orientation east had reduction of 4.91% and in São Paulo of 28.54%. The climate hottest and bigger solar heat, can explains the result. The orientation north also presented considerable difference, reduction of 31.84% for Belo Horizonte and 23.76% for São Paulo. Probably, it’s because the climate difference.

We can conclude that the glasses of the windows are significant for energy efficiency of the building. For a bigger energy efficiency, we must considered the place climate and the solar incidence in the construction, especially in the windows. The strong influence of the solar orientation of the window is shown by the results.

RESFEN showed adequate for the proposal situation, a fast calculation of model building thermal performance. With development of customizações for Brazil, this can be used for comparative degrees of energy efficiency of windows. A possibility is the development of Brazilian windows library, using software WINDOW 5 (LBNL), where the thermal properties of a shaped window are calculated, including glasses and frame, to be used in the RESFEN.

References


