The influence of envelope variables on energy consumption in buildings in Vitória, Brazil

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ABSTRACT: The awareness for energy efficiency in building sector has grown during the last years in Brazil and in the World. The new energy scenario brought to light the importance of energy efficiency in commercial buildings, encouraging discussions, studies and development of a new reality based on energy efficiency. This work aims to identify how some architectonic variables affect the energy consumption in commercial buildings, verticalized and artificially conditioned, in the city of Vitória, Espírito Santo. As methodology, a reference building was modelled based on the typical features of constructions located on the bioclimatic zone of study, which could be found in literature. Then, four variables of this building were altered: window to wall ratio (WWR), solar heat gain coefficient (SHGC), absorptance of opaque surfaces (α) and orientation of façades. The modelling and simulation of the cases were performed on the software DesignBuilder, an interface to EnergyPlus, a widely used Building Energy Simulation tool. The analysis considered the results of annual energy consumption and assessed the variation of the amount spent with air conditioning. The Window to Wall Ratio showed the highest impact on the energy consumption (12.4%), representing an increase of 32.3% on air conditioning spent. The impact of the other variables on total energy consumption followed the order: SHGC (8.7%), façades orientation (7.5%) and absorptance (4.0%). The difference between the highest and lowest total energy consumption out of all the cases analyzed reached 16.8%.

Keywords *energy efficiency, building envelope, thermo-energetic simulation*

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1. INTRODUCTION

In the last years, energy consumption has been on the spotlight of numerous researches. The world's dependence on energy has been increasing at an alarm rate, and the building sector has largely contributed to that growth (Martínez-Molina et al., 2016). In Brazil, the awareness for energy efficiency in commercial and public building sector has risen during the last years as a result of governmental actions and research projects (Bodach & Hamhaber, 2010). Therefore, this energy scenario brought to light the importance of optimizing the energy consumption in buildings, the motivation of this work.

The energy consumption in buildings is related to losses or gains of heat through the envelope. And associated with the internal load due to occupancy, equipment and artificial lightning, result in the air conditioning system consumption (Fossati & Lamberts, 2010). In fact, the building envelope have a great impact on energy efficiency and indoor environmental quality, being also an important component of building structure and have a great influence on their budget (Méndez Echenagucia et al., 2015).

There are several envelope variables that affect energy consumption in buildings, such as shape of the building, height, orientation, floor-to-floor height, internal loads, openings transmittance and shading coefficient, wall transmittance and others (Signor et al., 2001). Assessing their impact on energy consumption can be done applying thermal-energetic simulation, which has proven to be an effective and widely used tool for energy consumption evaluation.

In this context, the aim of this work is to identify how some architectonic variables affect the energy consumption in commercial buildings, verticalized and artificially conditioned, in the city of Vitória, Espírito Santo. The assessment was done through thermal-energetic simulation using the Design Builder software. The evaluation was done based on the variation of air conditioning consumption and total electricity consumption.

2. METHODOLOGY

The methodology of this research was based on the simulation method procedure, simplified in Figure 1. The choice of the software was based on literature review, which showed that the software EnergyPlus had an adequate applicability to this research. However, many users complained about the unfriendly interface of this software (Mendes et al., 2005). Therefore, to overcome this problem, a graphic interface for the EnergyPlus was chosen to perform the simulation, the DesignBuilder.

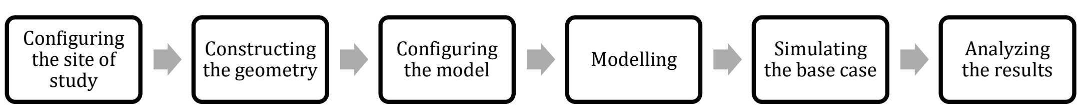

Figure 1. General method for modelling, simulation and analysis. Source: Adapted from Venâncio (n.d.)

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At first, the site of study needed to be characterized. The study is developed in Vitória, located on the coast of the Brazilian Southeast region, in the state of Espírito Santo, with coordinates 20°16'S latitude and 40°17'W longitude. The required climate data was obtained from the TRY (Test Reference Year) of Vitória, available in LabEEE (2016). The choice of this specific source was done because it had a more recent update (2005) than the other available sources and it has the proper configuration to input in the software.
To construct the geometry and to configure the model, a reference building was defined based on a study developed by Lamberts et al. (2006) which described the most widely used features in buildings located on the bioclimatic zone of Vitória: Zone 8. Additional data required were obtained from other sources, referenced in Table 1. A perspective drawing of the building and the plant are shown in Figure 2 and Figure 3.

Table 1. Characterization of the reference building.

Feature	Value	Source
Number of pavements	15 pavements	Lamberts et al. (2006)
Plant Shape	Rectangular	Lamberts et al. (2006)
Plant Dimension	30 x 15 m	Lamberts et al. (2006)
Solar Protection	Without protection	Lamberts et al. (2006)
Glass	3mm, clear, common	Lamberts et al. (2006)
Window to Wall Ratio (WWR)	40%	Lamberts et al. (2006)
Activity Type	Light, Metabolic rate: 0.9	Lamberts et al. (2006)
Orientation of the largest façade	North-South	Adopted by the author
Opening Hours	Fully occupied: 8am to 12am and 2pm to 6pm 50% occupied: 12am to 2pm	Commercial Hours
Occupation density	0.14 people/m^2	Brazilian standard NBR 16401
Lightning Load	6.4 W/m^2	Carrières (2007)
Equipment Load	9.7 W/m^2	Carrières (2007)

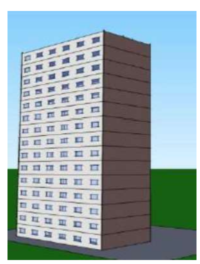
Figure 2. Perspective drawing of the reference building.

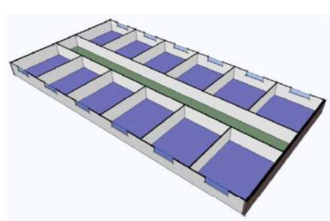
Figure 3. Perspective drawing of the pavement plant of the reference building.

The reference building also considered air conditioning system. The system was set to reach the control temperature of 24 °C, indicated by Ghisi & Tinker (2005).

In order to evaluate the impact of envelope variables on the climate consumption, it was necessary to select the parameters to vary and, therefore, evaluate their impact. To select

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those variables, a literature review was executed. In this paper, the studies developed by Signor et al. (2001) and Venâncio & Pedrini (2008) are highlighted.

Among the several envelope variables, Signor et al. (2001) selected the ten most relevant to energy consumption in Brazilian cities, based on sensitivity analysis. They are: Roof Area/Total Area; Façade Area/Total Area; WWR – Window to Wall ratio; PF – projection factor of windows overhangs; SC – shading coefficient of glazing; U_{roof} – roof transmittance and α_{roof} – roof absorptance; $U_{façade}$ – exterior wall transmittance and α_{facade} – exterior wall absorptance; and ILD – internal load density.

As the goal of the project was to analyze the typical buildings located in Vitória, the building geometry and the internal load density were kept the same. In addition, although the transmittance is an important variable, there is no real consensus of its impact on energy consumption using air conditioning (Carlo & Lamberts, 2008), therefore this analysis was not considered in this work. Windows overhangs were not considered as their use is limited in the existing commercial buildings of Vitória.

Venâncio & Pedrini (2008) quantified the influence of some architectural decisions on energy consumption and thermal performance of administrative buildings of the Campus of the Federal University of Rio Grande do Norte, and the orientation of the building has proven to be an influence factor. Therefore, additionally to the variables mentioned above, the orientation of the largest façade was considered.

Hence four variables were chosen to be studied: Window to Wall ratio (WWR), absorptance (α) for both roof and exterior wall, the Solar Heat Gain Coefficient (SHGC), which is used, as the shading coefficient of glazing, to evaluate the amount of the total solar heat gain that passes through the glazing, and orientation of the largest façade. The values of the variables used in the simulations are shown in Table 2 were used.

Table 2. Values considered in the simulations.

Variable	Values adopted		
SHGC	0.86	0.74	0.26
WWR	40%	60%	20%
α	0.40	0.30	0.70
Orientation	North-South	East-West	

The SHGC values of 0.86, 0.74 and 0.26 represent clear single glass (3 mm), clear double glass (3 mm) and reflective glass (3 mm), respectively. Absorptance of 0.30 corresponds to the yellow color, 0.40 to middle gray and 0.70 to dark green.

It is important to emphasize that for the reference building the following values were adopted for the variables: SHGC 0.86, WWR 40%, α equal to 0.4 and orientation North-South. To evaluate each variable, the reference building was used and only the parameter analyzed were variated in the ranges described in Table 2.

3. RESULTS AND DISCUSSION

3.1 Absorptance

Comparing the energy consumption values found varying absorptance (Figure 4), it is possible to see that as the absorptance increases, the energy consumption due to air conditioning rises 9.8%, increasing total energy consumption by 4.0%.

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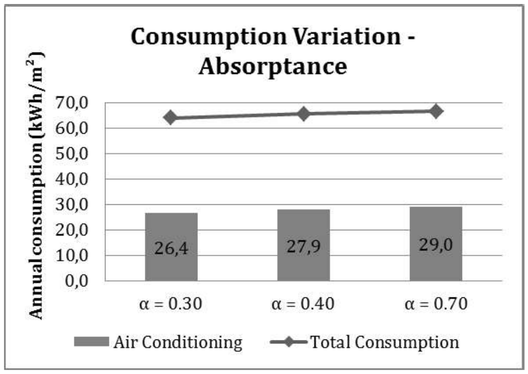

Figure 4. Energy consumption varying absorptance

Venâncio & Pedrini (2008) analyzed a building with WWR 40%, like the building in this study, and located in Rio Grande do Norte (5°45'54"S latitude and 35°12'05"W longitude). They found that the adoption of light colors, comparing to the base case with dark colors, reduced total consumption between 5% (rooms in South façade) and 6.1% (rooms in North façade). This result is fairly close to the result found in this work, and the small difference may be justified by the location of the buildings analyzed, especially the different latitudes.

3.2 Window to Wall ratio

As for the WWR, seen in Figure 5, the amount of energy spent with air conditioning systems increases when increasing the WWR. This growth reaches 32.3% comparing the cases with lowest and highest WWR (20% and 60%).

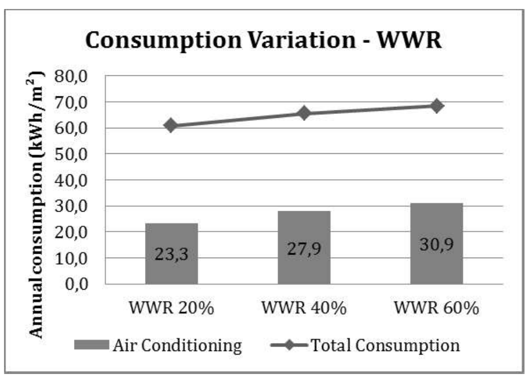

Figure 5. Energy consumption varying WWR

It is important to highlight that the other parameters of the reference building were maintained, and only the WWR was altered. Therefore, the orientation of this buildings is North-South and the values of SHGC and α are 0.86 (clear single glass) and 0.4 (Middle gray), respectively. It is possible to state that the clear glass contributes to the influence of the WWR, as it allows a greater amount of solar radiation to pass through the glazing, in such a way that an increase in openings area contributes greatly to the heat gain of the building. The increase in total energy consumption was 12.4%.

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3.3 Solar Heat Gain Coefficient

The variation of the SHGC, in Figure 6, increases 8.7% of the total energy consumption. The variation is insignificant comparing the results for SHGC of 0.74 and 0.86, that is, clear double glass and clear single glass, respectively.

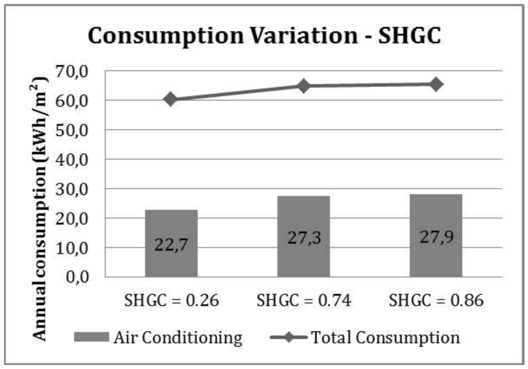

Figure 6. Energy consumption varying SHGC

Carvalho et al. (2010) analyzed a variation of the energy consumption in a building in Rio de Janeiro, with 40% of WWR, like the building analyzed in the present study. The authors found 18.79% of increase in air conditioning consumption when varying the glazing from reflective glass to clear glass (6mm). In the present study, an increase in air conditioning spent of 22.9% was found. The difference was considered acceptable considering the dissimilar pattern of the buildings analyzed in the two studies, especially the geometry, as the building analyzed by Carvalho et al. (2010) has 5 floors whilst the base case of this study is a 15-storey building.

Furthermore, according to Fossati & Lamberts (2010), the use of glazing with low shading coefficient (in this work the solar heat gain coefficient is addressed, proportional to shading coefficient) may increase the energy efficiency in a building, especially if used along with other strategies.

3.4 Orientation

Figure 7 shows the energy consumption when varying the orientation of the largest façades. Changing the orientation to East-West promotes an increase of 17.5% of the energy consumption by air conditioning due to the increase in solar heat gain. The impact in the total energy consumption was 7.5%.

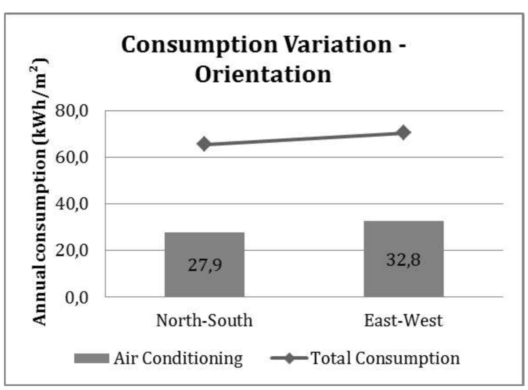

Figure 7. Energy consumption varying orientation of the largest façades

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Fossati & Lamberts (2010) highlight that the orientation of façades is an important variable when linked to the WWR. In the present study, the WWR of the reference case is significant (40% of the total area, 60% of the main façades), in such a way that the orientation has an important effect.

3.5 Variables influence comparison

Table 3 shows the results of all the cases simulated. Out of the variables analyzed - WWR, absorptance, SHGC and orientation - the Window to Wall Ratio showed to have the highest impact on the energy consumption. The variation of air conditioning energy consumption reached 32.33% while varying this parameter. Fossati & Lamberts (2010) also concluded that the WWR is the most relevant measure to energy conservation and, as the WWR increases the energy efficiency tends to decrease, when no other energy conservation measure is adopted to minimize this effect.

The impact of the other variables on the total energy consumption can be organized in the following order: SHGC, 8.7% on total energy consumption and 20.3% on air conditioning consumption; façades orientation, 7.5% on total energy consumption and 17.5% on air conditioning consumption, and absorptance, 4.0% on total energy consumption and 9.8% on air conditioning.

Table 3. Comparison between all the simulated cases

Variable		Air conditioning Annual Consumption (kWh/m^2)	Total Annual Consumption (kWh/m^2)
Absorptance	α = 0.30	26.4	63.96
	α = 0.40	27.9	65.47
	α = 0.70	29.0	66.54
	Difference	9.8%	4.0%
SHGC	SHGC = 0.26	22.7	60.26
	SHGC = 0.74	27.3	64.86
	SHGC = 0.86	27.9	65.47
	Difference	20.3%	8.7%
WWR	WWR 20%	23.3	60.88
	WWR 40%	27.9	65.47
	WWR 60%	30.9	68.42
	Difference	32.3%	12.4%
Orientation	North-South	27.9	65.47
	East-West	32.8	70.36
	Difference	17.5%	7.5%
Comparison	Highest	22.7	60.26
	Lowest	32.8	70.36
	Difference	44.5%	16.8%

The lowest consumption (60.26 kWh/m^2.year) corresponds to the building with the lowest SHGC and the highest consumption (70.36 kWh/m^2.year) was the case with the East-West façade orientation. The consumption variance reached 16.8% and up to 44.5% for the air conditioning consumption. This corresponds to 68184.8 kWh/year, a saving of R$ 18737.86 each year, considering the tariff in Vitória in April 2016.

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4. CONCLUSION

This study assessed the impact of four variables in the total energy consumption of a building considering a base case, they are: Window to Wall Ratio, absorptance, Solar Heat Gain Coefficient and Orientation. The Window to Wall Ratio showed the highest impact on the energy consumption (12.4%). The air conditioning energy consumption varied 32.3% when changing this parameter. The clear glass contributes to the influence of the WWR, as it allows a greater amount of solar radiation to pass through the glazing, in such a way that an increase in openings area contributes greatly to the heat gain of the building.

The impact of the other variables on total energy consumption followed the order: SHGC (8.7%), façades orientation (7.5%) and absorptance (4.0%). The difference between the highest and lowest total energy consumption out of all the cases analyzed reached 16.8%, with a 44.5% reduction in air conditioning spent. This savings can represent a reduction in energy consumption of 68184.8 kWh/year.

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