The influence of the window in energy consumption: A study in multi-family residential buildings

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ABSTRACT: The urbanized areas around the whole planet have grown increasingly and according to the United Nations, the expectation is that over 70 % of the population are located in the urban centers by 2050. This growing evolution of cities boosts the energy consumption in all productive sectors and it is expected a continue growth for the coming decades. The research analysed the thermal performance of a naturally ventilated environment with different windows models, considering the quantitative Thermal Discomfort Frequency FDT (Frequência de desconforto térmico) in relation to the kilowatt hour (kWh) consumption for cooling in multifamily dwellings, Vitória / ES. There were three methodological steps: firstly, it was set up the evaluation periods, the parameters of the american standard American Society of Heating Refrigerating and Air conditioning Engineers (ASHRAE 55), the model , characteristics and physical properties of materials, with the software Design Builder. In the second step simulations were performed and in the third step it was compared the FDT in relation to the energy consumption for cooling. The results obtained by Nico -Rodrigues methodology (2015) demonstrated that the consumption of kWh for the proposed window model is smaller than the most widely used model due to the use of natural ventilation as a cooling factor and also the use of shaders. The use of components that allowed the constant ventilation and the use of shaders on the window, were important factors on improving the thermal performance of the building, demonstrated by the decrease of 36.44% of the amount of kWh needed for cooling.

Keywords *Efficient windows; energy consumption; thermal discomfort frequency*

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1. INTRODUCTION

With a Growing global urbanization, challenges for sustainable development will be potentially concentrated in cities, and according to the United Nations (United..., 2014) the projections show that the urbanization, associated with the growth of the world population will be able to bring approximately 2,5 billion people to the urban areas by 2050. This urban growth influences the internal characteristics of the environments, which increasingly rely on mechanical cooling or heating systems. The solutions to improve environmental comfort are essentials, since people spend between 80% and 90 % of their lives indoors (Rupp; Vásquez; Lamberts, 2015).

This situation highlights the need for strategies aimed at energy savings in the civil construction. The National Program for Energy Conservation – PROCEL (Prorama Nacional de Conservação de Energia Elétrica) - (Programa…, 2015), estimates a consumption reduction potential of approximately 30 % with the implementation of energy efficiency measures in lighting, air conditioning and architectural interventions in the envelope, for existing buildings. This percentage rises to 50 % in new buildings, according to the National Energy Efficiency Plan (Ministério…, 2015).

According to the National Energy Balance – (BEN – Balanço Energético Nacional) - (Balanço…,2015), year base of 2014, the final energy consumption increased by 2.9 %, and the sectors that most contributed were the residential and the commercial, with an increase of 5.7 % and 7.4 %, respectively. In the residential sector, among the most consumer equipment is the air conditioner. Data from the last survey on equipment ownership and usage habits (Eletrobrás, 2007), year base of 2005, showed that the air conditioners are responsable for 20% of the electricity consumption in the residential sector, highlighting the refrigerator with 22% and the shower with 24%.

In commercial buildings it was found that the use of natural ventilation reduced by 40% the energy consumption when compared to mechanically chilled environments. They also found that the use of nocturnal ventilation is an effective method for mitigating the thermal conditions in the environments. (Stavrakakis et al., 2012, Faggianelli et al., 2014). For Rupp & Guisi (2012), the results obtained with hybrid ventilation in commercial buildings in Florianopolis, within one year, determined that even with 31.9 % of energy savings there could be dissatisfied users in the hottest season, thus requiring the use of air conditioners.

For Stavrakakis et al., (2012) the energy cost of a naturally ventilated building is 40% lower than a building with air conditioning and strategies for natural ventilation are more effective when you have a better use of local conditions. It appears that the benefits of making use of natural ventilation are of great importance in reducing energy consumption and improving environmental thermal conditions, beeing the main strategy for controling the thermal comfort in residential environments located on tropical climate. (Yao et al., 2010, Kim; Park, 2010, Yin et al., 2010, Pereira; Ghisi, 2011, Faggianelli et al., 2014).

The NBR (Brazilian Standard) 15.220 (Associação..., 2005) prescribes the guidelines for the use of ventilation in seven of the eight bioclimatic zones, not recommending ventilation only for the zone 1, being the cold region of the country. Natural ventilation as a passive thermal conditioning has the ability to provide indoor environments more thermally pleasant when compared to artificially conditioned, and as a passive strategy is one of the solutions to achieve more sustainable buildings (Lamberts; Dutra; Pereira, 2014).

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Thus, this research has analysed the thermal performance of a naturally ventilated environment with different windows models, considering the quantitative Thermal Discomfort Frequency (FDT) in relation to the kWh consumption for cooling in multifamily dwellings in Vitória/ES. The windows used were based on the models defined by Nico - Rodrigues (2015).

2. METHODOLOGY

There were three stages carried out: definition of evaluation periods, parameters of american standard, American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE 55) model and the characteristics and physical properties of the materials; simulations, considering the operating temperature as an evaluation factor; and determining the FDT, and the kWh values for cooling.

2.1 Design and the physical properties of the materials

For comfort temperature reference (Figure 1) it was used parameters defined by ASHRAE 55 (American..., 2004) for adaptive comfort with 90% acceptance by setting the operating temperature that varies according to the external air temperature.

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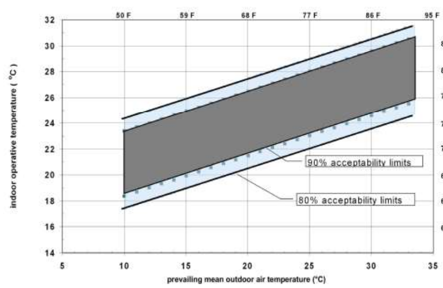

Figure 1 – Comfort temperature limits. Source: Adapted from ASHRAE (2004).

The model has five floors, with pilotis on the ground floor and apartments type consisting of two bedrooms, living room, kitchen, laundry area and bathroom (Figure 2) of approximately 70 m², highlighting to be the most commercialized type in the region of the city of Vitória (Sindicato..., 2016). The environment analyzed was the dorm showed in Figure 2

The use of natural ventilation was justified by the predominance of wind in the NE quadrant with more speed frequency of 3, 6-5, 7 m / s, which, according to Lamberts, Dutra and Pereira (2014) allows the use of natural ventilation as a resource to alleviate the thermal discomfort, especially in the warmer months.

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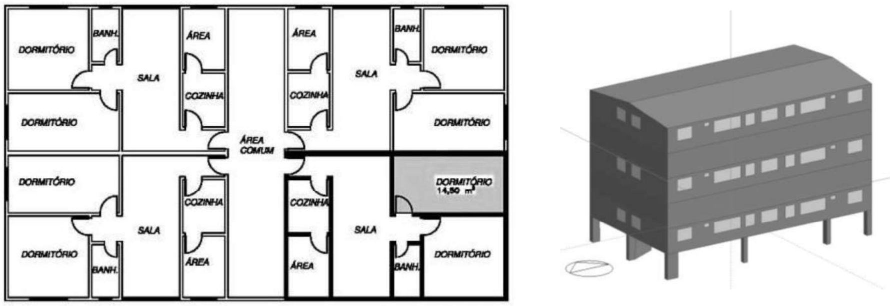

Figure 2 – Floor plan and 3D view of the building. Source: *Design Builder* (2015).

The reference values used the thermal properties of the building components of the envelope, the dress characteristics and the type of activity performed by the user defined by the brazilian standard NBR 15220-3 (Associação..., 2005) and by the brazilian standard NBR 15575-4 (Associação..., 2013b), on Table 1. The choice of the clothes and activities are related to the summer, considered to be the hottest season and the one that needs further studies to obtain thermal comfort.

The dimensions of the windows follow the brazilan standard NBR 15575-4 (Associação..., 2013b), considering 8% of the floor area to the Southeast region. The windows are located on the outer walls and the window sill height is 1.0 meter. The room door is the second element to allow cross ventilation.

Table 1 **:** Details of the layers of the walls and slabs with the material properties . Source : drawn from the Brazillian Standard NBR 15575-4 (ASSOCIAÇÃO..., 2013b).

Dimensions – Area of the room = 13,00m²	
Windows dimensions and areas	1,80m x 1,30m = 2,34m²
Ventilation area M1	1,17m²
Ventilation area M2	1,17m² de ventilation through the shutters
Walls thermal transmittance (U)	1,76 W/(m².K)
Emissivity (Ɛ) of the walls and floor	0,9
Absorptance (α) of the walls and floor	0,3
Thermal transmittance glass inc. 6 mm (U)	5,77 W/(m².K)
Ocupation density	0,14 person/m²
Clothing	0,5 clo
Metabolism activity - reading	115 W/person
Standard occupancy: 2 people	**Day** 100% (7h00 – 10h00) 50% (10h00 – 12h00 e 16h00 – 19h00) 0% (13h00 – 16h00)
	Night 100% (24h00 – 7h00) 50% (19h00 – 20h00)
M1 – window commonly used in buildings	**8h00 – 21h00 -** 100% window opened = 50% of the opening **21h00 – 8h00 –** closed window – 0% of the opening = c l o s e d 50% of the opening with glass
M2 – window indicated by Nico-Rodrigues (2015) With glass	**24 horas -** 100% window opened = 50% of the opening closed with glass
With shutter	**08h00 – 21h00 -** 100% window opened = 50% of the opening overrides the glass **21h00 – 8h00 –** window closed – 0% of the opening closed 50% with shutter
Obs.: the sliding opening system allows a maximum of 50% of opening on the window	
Artificial lighting	5 W/m²

The windows models used in the simulation have the following characteristics: The M1 model, commonly used in buildings according to Nico -Rodrigues (2015), has a frame, two

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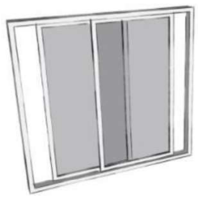
sheets with glass and a sliding system without sun protection; and the model M2, considering the same dimensions, has shutters that provide shade in the width of the window considered by Nico- Rodrigues (2015) a model of window much more efficient (Figure 3)


Model M1


Model M2

Figure 3 – Windows models analysed in the simulations. Source: Nico-Rodrigues, 2015.

2.2 Simulations

The simulations were performed using the software Design Builder and it was modeled on a multifamily residential building, located in the city of Vitória, Espírito Santo. The climatic conditions of the city were analyzed by the weather file TRY (Test Reference Year) from 2000 to 2010 (Laboratório..., 2012). During the simulations they were analyzed performing thermal conditions with the use of two types of windows.

The simulations were performed for the 1st floor (on pilotis), and the orientation of the window facing the west, according to the results obtained by Nico-Rodrigues (2015) as being the worst situation for the summer season. The simulations took place in the summer period (21/December - 21/March = 91 days) because it is the hottest in the region, as defined by the brazilian standard NBR 15575-1 (Association..., 2013a), and for 24 hours of the day.

2.3 Comparison of frequencies (FDT) in relation to the energy consumption for cooling

For the analysis of the results from the simulations it was used the Thermal Discomfort Frequency (FDT), which is equivalent to the percentage of time, full time, in which the operating temperature is above the maximum of the comfort temperature established by the ASHRAE 55 (American..., 2004). This index is mentioned in the European Standard EN 15251 (European..., 2007) based on the adaptive comfort concept and also the Quality Technical Regulation (RTQ – Regulamento Técnico de Qualidade) (Brazil, 2012), and the POC (percentage of comfort hours) index with similar concept.

This indicator quantifies the hours of discomfort in the unit of percentage for a certain time interval, and the maximum value, refers to the maximum time limit. In this research, the proposal was to analyze daily periods, (24 hours) corresponding to the maximum discomfort frequency of 100%. Thus, by dividing the maximum frequence of 100 % for 24 hours, we have the equivalent of 4.16% of thermal discomfort for each hour of the day.

When natural ventilation is not sufficient to maintain the temperatures on the limit or below the comfort temperature limit defined by ASHRAE55 (American..., 2004), it was used a mechanical refrigeration. In order to reach the comfort conditions, the equipment was selected with energy efficiency criteria of the National Institute of Metrology, Quality and Technology (INMETRO – Instituto Nacional de Metrologia) (Instituto..., 2016), having the

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stamp “A”- best possíble - of the National Program for Energy Conservation (Procel – Programa Nacional de Conservação de Energia Elétrica) (Programa, 2015). The selected model was a Consul CCY12D, of window, 12000 BTUs, Cold.

For the quantitative definition of kWh it was considered the sum of the FDT (Σ %) over the 91 days simulated. This value was converted in hours (divide by 4.16%), resulting in the number of discomfort hours that required the use of mechanical refrigeration. To define the number of kWh consumed in this period, it was used the power consumed by the device, according to manufacturer's data, which is 1,125 kWh (Consul, 2016). This value multiplied by the number of hours of discomfort, considering the 91 days simulated, gave the required power consumption for the air conditioner to maintain the comfort temperature set by the ASHRAE 55.

3. RESULTS E DISCUSIONS

The results follow presented in two parts: first, with the Thermal Discomfort Frequency (FDT) for each month of the summer and for each window model. The second, with graphics of the quantity of hours and kWh for each window model.

3.1 Thermal Discomfort Frequence (FDT) of the months and the window models

To obtain and compare the results it was used the temperature parameters established by the ASHRAE55 for each month of the summer (Table 2)

Table 2: Temperature parameters for the ASHRAE 55. Source: The authors, 2016.

Months	Montlhly average temperature of outside air (ºC)	Neutral temperature (ºC) Tn=0,31(Te)+17,8	Range comfort temperature (ºC) ASHRAE 55 90% acceptability	ASHRAE Comfort temperature ºC
December	26,86	26,12	23,61 – 28,61	28,61
January	26,35	25,96	23,45 – 28,45	28,45
February	25,76	25,78	23,27 – 28,27	28,27
March	26,65	26,06	23,55 – 28,55	28,55

With the simulation results (Table 3) it was compared the FDT for each model over the summer months. The results of the model M2 showed a significant decrease in discomfort hours, 631.02 hours less of discomfort when compared to M1. This difference occurred because the shutters used in the M2 model allowed the glazed and the opened areas to be shaded. As well as the constant ventilation, provided by the model.

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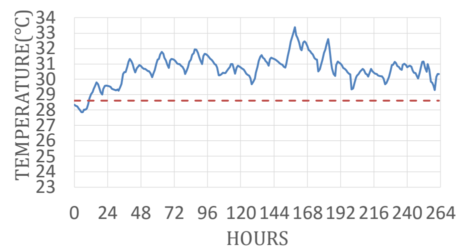
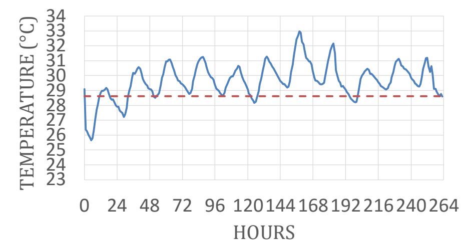
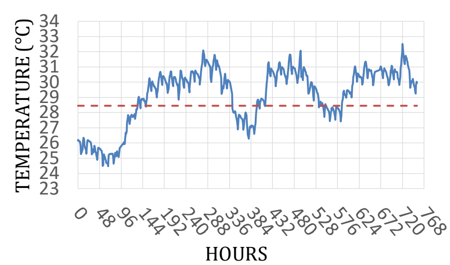
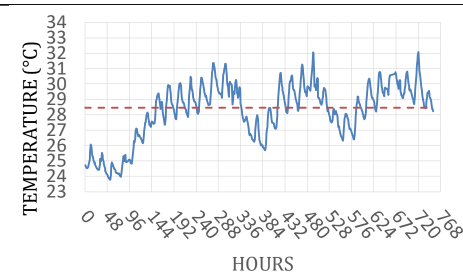
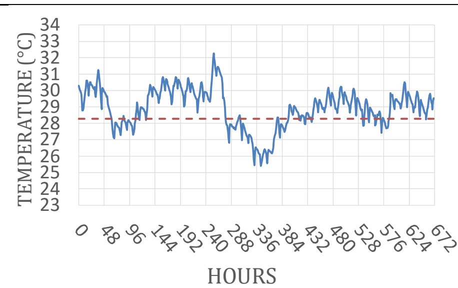
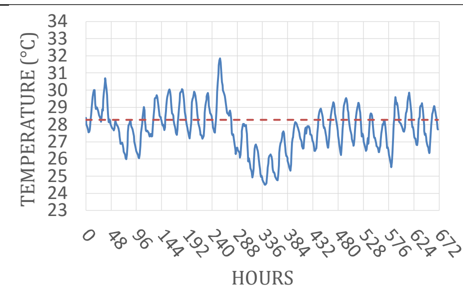
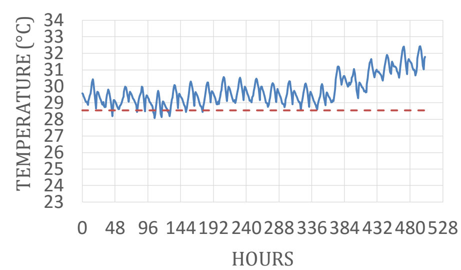
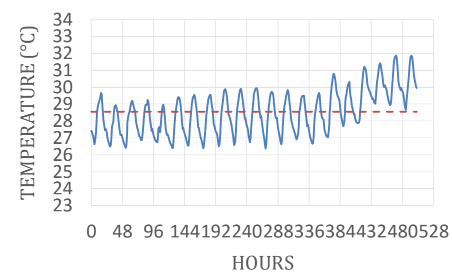
Table 3 – Thermal Discomfort Frequence in the summer months. Source: The authors, 2016.

	M1	M2
21 - 31/DECEMBER		
01 - 31/ JANUARY		
01 - 28/FEBRUARY		
01 - 21/ MARCH		
	Operating Temperature (°C)	ASHRAE Comfort Temp. (°C).

All months showed improvements in the results using the M2 model (Figure 1). In December, referring to 11 days evaluated, there was a decrease of 31 hours of discomfort. In January, the results showed a lower percentage of hours in discomfort when compared to other months, with 99.16 hours. The month of February gave the best results for the28 days simulated, and there was a reduction in the thermal discomfort of 264.42 hours. During the month of March, 21 days were simulated, and the results were also significant, resulting in 236.17 hours less of thermal discomfort when compared to the M1 model.

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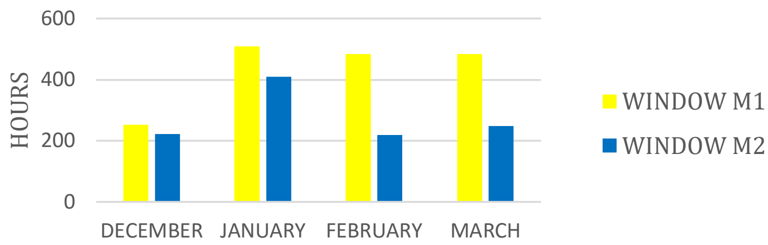

Figure 1 – Discomfort hours for each month of the summer. Source: The authors, 2016.

3.2 Energy consumption in relation to hours of discomfort

The results of the Thermal Discomfort Frequence (FDT) allowed to quantify the kWh required to reach the set comfort temperature (Figure 2). The M1 model had a total of 1731.34 hours in thermal discomfort during the summer period, which resulted in a consumption of 1947.76 kWh to maintain the comfort temperature defined by ASHRAE 55. The model M2 had a total of 1100.32 hours in thermal discomfort, resulting in a consumption of 1237.86 kWh of energy with the use of the air conditioner.

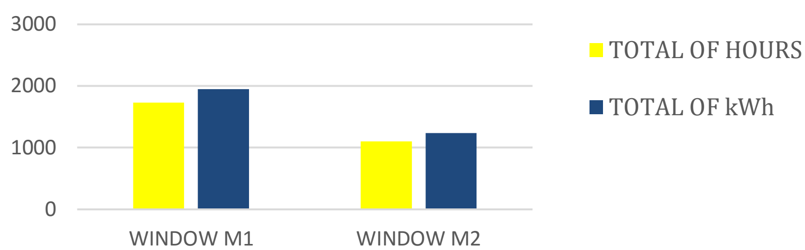

Figure 2 – Energy consumption for the hours of discomfort. Source: The authors, 2016.

The improvement provided by the model M2 represented 631.02 hours less in thermal discomfort over the summer months, which resulted in 36.44% of energy savings only for the four simulated months. The results obtained reaffirm the necessity of the windows to be shaded and mainly with a constant ventilation, essential factors for reducing the amount of energy required to cool the simulated environment.

4. CONCLUSIONS

The use of natural ventilation is one of the factors that most influence the energy performance in buildings, when the conditions for the use of the same are favorable and described as guidelines in the regulations. It was observed that the proper use of opening elements is critical to the influence of ventilation in the building performance. Even though the temperature parameters defined by ASHRAE have controversies regarding its use for tropical climates, they are still the parameters that record the most consistent results with reality. The adoption of adaptive actions by the user are attitudes that improve the thermal sensations, resulting in the acceptance of higher comfort temperatures.

The results of the Thermal Disconfort Frequence defined for each window type was crucial to ensure the efficient use of the windows, becoming decisive to the improvement of the internal conditions. The M2 model showed less need for air conditioning use, as a way of

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achieving the conditions for thermal comfort, recorded by the quantitative of KWh. From the results obtained, it can be said that the most common window in multifamily residential buildings is not adequate and demonstrates poor performance for thermal comfort, indicating environments with the need for mechanical cooling use and thus increasing the energy consumption. The guidelines described in the performance standards recorded the need for the use of ventilation and openings that allow its influence on the environment, which mainly aims at reducing energy consumption.

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