The influence of glazed balconies in the thermal comfort in an urban tropical region

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ABSTRACT: Natural ventilation has served as an effective passive cooling design strategy to comfort and reduction energy used by air-conditioning systems, especially, for tropical regions where the temperature and humidity are generally high. The balconies are architectural elements characterized by shaded areas and permanent ventilation with a significant impact on comfort and distribution of air flow inside the building. This research aims to analyze the thermal performance of what is becoming a very common practice of glazing of the balconies in Vitória, a tropical city localized in southeast of Brazil. The nuisance caused by air pollution in this region, accounts for up to 25% of the complaints to the local Environmental Agency can be the main motivation in the glazed balconies in the vertical residential buildings by the population. The methodology procedures included outdoor and indoor measurements of temperature, air humidity and air velocity in three balconies apartments. The average air temperature of 24 hours in the glazed balconies was 2° C higher than the average outdoor temperature and there was a reduction indoor ventilation rate. The balcony microclimate is altered negatively by the glass heat retention capacity and it was registered that 80% of the hours of the day not attend the comfort zone. Thus this practice it is not recommended for hot climates. The results probably contribute to the discussion about the illegal practical of glazed balconies in some Brazilian urban areas and their thermal comfort consequences.

Keywords *Thermal comfort, balconies, tropical region*

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1. INTRODUCTION

The tropical regions are determined in part by their temperature, which in turn is defined to be within two limits values: the temperature of 20°C, as annual average, and maximum temperature of 43° C in the hottest season. Specifically, for the tropical regions of hot, humid weather, the average temperature is 18° C, while the maximum temperature is 38°C approximately, being the most striking aspect in this type of weather the high humidity, which often reaches 90%. This climate is found generally in countries close to the line of Ecuador, such as Brazil (Hertz, 2003).

The adaptation of buildings to climate is defended by the precepts of bioclimatic architecture that prioritizes aspects related to environmental comfort consistent with the potential of the environment, being in the tropics prioritized aspects related to the thermal comfort (Corbella & Corner, 2011). In this sense, the large supply of solar radiation and the high humidity in this climate requires the adoption the shading and ventilation of spaces, as basic premises.

The ventilation deserves special attention, and since respected their boundaries and other constraints of the surroundings, normally the building and the urban spaces should be as open as possible in order to provide better health conditions and comfort to users of spaces and passers-by of urban streets. In addition to the shape of the building, various elements and architectural components can be used to adapt the building to the climate. In Brazil, the concern of adaptation to the climate began with the effort of the colonist and the European immigrant in the construction of their homes:

> *Here, the Portuguese moved its location to the balcony, where I ate, talked and was napping in a well ventilated network of large meshes. (Corbella & Corner apud, Lemos, 1978)*

Balcony is a terminology applied to architectural spaces of different morphologies, where the same term is used synonymously with porch, among many others, result of the function of this element in the various periods of history being used in accordance with the context of each moment (Barro & Martins, 2007). However, regardless of the historical context, the main feature of Brazilian balcony is being a nice, shaded and ventilated spot, which was acquiring certain habits and accumulating functions over time, being one of the main living areas of the family.

The invention of reinforced concrete and the elevator at the end of the 19th century caused the verticalization of construction and a new type of housing: the apartment buildings. However this verticalization did not extinguish this Brazilian house space, which can be found with adaptive climate concerns, for example, in the works of Guinle Park of Lúcio Costa and the Accommodation of the Boulder of Eduardo Reidy, that even at the end of the first half of the 20th century, when the topic was modernity, they were still showing the balconies (Barro & Malik , 2007).

Thus many studies have investigated the importance of this architectural element in the environmental comfort and the energy efficiency of the building. Prianto & Depecker (2002) evaluated the effects of the balcony, the openings and the internal division of

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compartments in indoor air speed on a building located in a region of tropical humid climate. The results showed that the settings of the openings and the shape of the balconies are more efficient in the growth of the movement of air through the natural ventilation of the internal division of the building, and that such factors should be taken into consideration in the design of buildings with hot, humid weather. Ai et al. (2011) stated in their study that the presence of a balcony in architecture has a number of effects on the environmental performance of a building, such as ventilation and natural lighting, shading, the thermal comfort and transport of pollutants. The authors reiterate that this element is able to improve the uniformity of the air distribution in the environment. Montazeri & Blocken (2013) evaluated through simulations, using the Computational Fluid Dynamics, the wind pressure distributions on the surfaces of a building with and without balconies. The results found by them reaffirm that the balconies are responsible for strong changes in the distribution of wind pressure on the facades.

On the other hand, the use of this passive architectural feature of environmental comfort may be suffering a threat, losing place to increasingly closed constructions due to the nuisance caused by noise and air pollution in major urban centers. Currently, a very common practice in residential buildings of Brazilian metropolises is closing the openings balconies with glass, thus mischaracterizing one of the main architectural elements in subtropical climates. One of the most iconic examples is the Design of the South Atlantic Condom in Rio de Janeiro, erected in 1979 and designed by architect Shlomo Wenkert. This project was awarded internationally, being that the design envisaged large and open balconies in which all would have a small circular pool, however, in a short time the project has been distorted from its original intention, being carried out the closure of these openings (Teixeira, 2014). This practice is also observed in other tropical countries, for example, the closure the balconies with glass on Lebanon and its influence on thermal comfort, as reported by Saleh (2015).

In this context, this study aimed to investigate the thermal comfort in balconies located in the city of Vitoria, Brazil, whose openings have been glazed. Although the code of local works establishes in its article 140, § 4° that "the openings of the balconies may not be closed for squares" (PMV, 1998), this has become very common in residential buildings in the region, mainly due to the disruption caused by the dust, the subject of constant complaints from residents and workers to the local Environmental Agency (Machado et al., 2014).

It is important to note that often, as in the case of the municipality of Vitória, the balconies are designed considering some constructive advantages proposed by the Guide Plans – which, correctly encourage their use – but who are already idealized considering its possible closure, misrepresenting so both the original concept of the function of the balcony as their urban benefit to provide greater integration between interior and exterior. The preset article reports the initial results of a broader research whose aims are related to the discussion of thermal performance of the element balcony as well as the indoor air quality of environments contiguous to it.

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2. METHODOLOGY

For the development of research, considering that the methodology was developed based on *in loco* measurements, one of the main issues to be considered was the choice of balconies in similar environmental conditions, in order to the combined analysis of measured data.

The main parameters considered as stakeholders on the results were the characterization of study region and the environmental parameters, as detailed below.

2.1 The region of study

Vitória (LAT 20° 19 ' 10 "S LONG 40 20 ' 16" W), the capital of state of the Espírito Santo (ES), is located on the southeast coast of Brazil and has approximately 327,801 inhabitants (IBGE, 2010). The region has experienced an intense process of economic and urban growth in recent years. It has the third largest port system of Latin America, and several industrial plants, such as mining, pelletizing, extraction of stone, cement and food.

Three balconies with the same dimensions of a residential building located in the Jardim Camburi, Vitória, ES, were monitored in autumn from 03 April to 20 may 2016. The Residential Condom is located next to large vehicular flow, such as Dante Michelini Avenue and the Norte-Sul Highway, as well as to the main industrial region steel pole (Figure 1a). Measurements occurred on a balcony of the column 1 at the 20th floor (South) and two balconies in columns 5 and 3 (Southeast) at 10th and 20th floor respectively (Figure 1b). These balconies had their openings closed with colorless toughened glass shutters of 8 mm (Figure 1c and Figure 1d).

Figure 1. (a) Emphasis on monitored building and (b) the distribution scheme of the apartments with the location of the monitoring points in columns 1, 3 and 5. Emphasis the balconies. Source: adapted from Galwan (2016). (c) balconies in the southeast facade (d) Glazed balcony of 10th floor.

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In addition to glazing, balconies monitored have blinds that are closed most of the day. None apartment reported the total opening of the shutters, but were reported "generally" and "almost always" the minimum opening of one of its parts.

2.2 Environmental parameters

On monitoring of environmental parameters on the internal balcony was used a weather sensor (Grimm Technologies, Germany), belonging to the Department of Environmental Engineering at the Federal University of Espirito Santo - UFES, previously calibrated, able to record and store data of temperature, air humidity and wind speed at intervals of 1 minute (Figure 2). The equipment was located centrally in the environment at a height of approximately 1.50 m. Three experimental, not simultaneously campaigns were performed, each with minute-by-minute records, for 24 hours, over six consecutive days for each balcony.

Figure 2. Meteorological sensor used on monitoring the balconies

Outside, these parameters were acquired by Rede de Estações Meteorológicas Automáticas (*Automatic Weather Stations Network*) of the Instituto Nacional de Meteorologia (INMET), from the Automatic Station located at the Federal University of Espírito Santo, in the Goiabeiras neighborhood, near the region of study (Figure 3).

Figure 3. Weather Station of INMET located in UFES, Brazil (INMET, 2016).

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The data collected through the Station's sensors are stored in a data-logger and made available to the public in an open and free of charge way on the internet (INMET, 2016). Hour means were used throughout the 24 hours, concurrent to the three experimental campaigns held in each apartment in order to allow the comparison of internal and external data and assessing the influence of the closure of the balcony.

3. RESULTS

The mean of 24 hours of the internal and external environmental parameters, for each day of monitoring, is presented in Table 1. It is noted that the 24 hours mean (28°C) for air temperature in glazed balconies is at least 2°C higher than the 24 hours mean for the outdoor temperature (25.7°C). Considering the comfort zone for people with normal clothing ranges from 23 to 27°C (ISO 7730/2005) and that in warm weather countries the external temperature means is high most of the time, this increase caused by glazing of balconies is significant in the influence on the human discomfort and the thermal environmental gain.

Table 1. 24 hours mean for the environmental parameters measured indoor and outdoor balconies.

		Indoor			Outdoor			
Sample date	**Floor**	**T (°C)**	**R.H (%rH)**	**Air velocity (m/s)**	**T (°C)**	**R.H (%rH)**	**Air velocity (m/s)**	**Wind direction**
04/03/16	10th	31.4	58.4	0.30	27.7	76.1	1.46	S
04/04/16	10th	31.5	59.1	0.14	27.7	77.0	1.45	S
04/05/16	10th	31.1	58.8	0.01	26.4	79.6	1.19	SO
04/06/16	10th	30.4	58.6	0.13	26.0	79.8	1.34	SO
04/07/16	10th	30.5	54.6	0.26	26.7	75.0	1.63	SO
04/08/16	10th	31.1	54.2	0.26	27.2	73.8	1.40	SO
05/01/16	20th	24.8	57.8	0.11	22.5	66.3	2.05	S
05/02/16	20th	25.4	50.3	0.00	22.8	56.3	1.58	S
05/03/16	20th	26.2	58.8	0.00	22.3	78.5	1.37	SO
05/04/16	20th	27.0	61.3	0.00	24.4	75.0	1.42	SO
05/05/16	20th	26.4	62.3	0.00	24.1	71.5	1.32	S
05/06/16	20th	26.6	62.0	0.00	23.9	76.8	1.37	SO
05/15/16	20th	25.3	62.6	0.23	27.4	75.6	1.84	SO
05/16/16	20th	27.5	57.0	0.30	26.5	73.5	1.57	SO
05/17/16	20th	28.2	63.7	0.00	26.4	81.7	1.30	SO
05/18/16	20th	28.0	65.6	0.03	26.9	79.9	1.37	S
05/19/16	20th	26.7	66.8	0.10	26.2	81.0	1.18	S
05/20/16	20th	26.7	70.0	0.09	27.0	73.8	1.92	S
Mean		**28.0**	**60.1**	**0.1**	**25.7**	**75.1**	**1.5**	
SD		**2.33**	**4.78**	**0.11**	**1.83**	**6.00**	**0.24**	
Min		**24.8**	**50.3**	**0.0**	**22.3**	**56.3**	**1.2**	
Max		**31.5**	**70.0**	**0.3**	**27.7**	**81.7**	**2.0**	

The 24 hours mean for the relative internal air humidity in the balcony is a decrease in relation to the 24 hours mean for the air humidity in the external environment (60 and 75%, respectively), probably due to the temperature increase within the environment. The 24 hours mean for the air speed reaches up to rate at least 90% less internally (0.1 m/s)

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than outdoors (1.5 m/s). This result reinforces the fact that the closure of openings of the balconies, which by virtue of municipal law should be permanent ventilation areas, do not show a good performance in warm climate countries, as it increases the temperature beyond the recommended comfort range, and it reduces the natural ventilation rate.

Figure 4 shows the hourly means of the temperature, air humidity and wind speed of the three balconies over the days of the week. It can be observed that the maximum temperature average values registered are internally to the balconies in the mornings around 9:00 and 10:00 a.m., reaching to a maximum mean value of 30°C in this interval of the day. That fact can be explained by the main orientation of the balconies, receiving the highest solar radiation in the morning. However, it is important to emphasize that the outside temperature mean in this same time reaches the maximum value of 27°C. Thus it can be stated that glazing balconies facing this orientation alters the microclimate of the environment increasing up to 3°C the temperature in the morning. It should be highlighted the fact that the monitoring was conducted during the fall, which means to say that probably in the summer this temperature rise can be even higher.

As it was expected, the highest mean values of the outdoors air temperature, considering the three experimental campaigns, were in the afternoon around 1:00 pm, time in which the solar radiation is more intense, reaching a value of 29°C, in average. It is interesting the fact that, although the orientation of the two balconies is Southeast, i.e. there is no direct solar incidence on those facades in the afternoon, the balconies show internally temperatures similar to the outside world, in the same time interval.

From that time the temperatures start to fall both in the external environment as the internal one. The lowest temperatures are recorded at night, being the minimum mean values found during the morning around 5:00 a.m. However, while during this period are recorded temperatures means around 21°C, the minimum mean values of temperatures recorded at the same time on the balconies reach to 26.4°C, which shows a significant thermal retention capacity of the glass in relation to the radiation received during the day. Another fact of the utmost importance in the evaluation of the interference of that element in the architecture of the residential buildings is the observation that, in approximately 80% of the daily hours, on average, the balconies monitored are out of range of the thermal comfort.

The city of Vitoria shows high relative humidity rates and may reaches mean values in the external environmental above 90% at night. However, due to heat retention capacity by the balcony glazing, the internal relative humidity mean of these locations at night does not exceed 67%. During the period of the day, however, the difference of the air humidity of the external and internal balcony is lower.

On analysis of the hourly mean of the wind speed it can be observed that even with the possibility of full opening of the glass blinds by the residents, they prefer to keep most of them closed, resulting in low or null values in relation to air movement rate within these environments.

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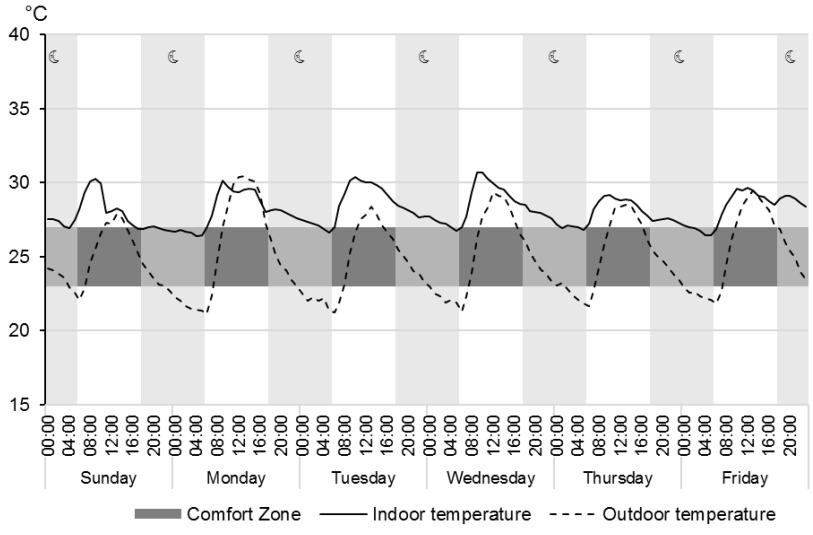
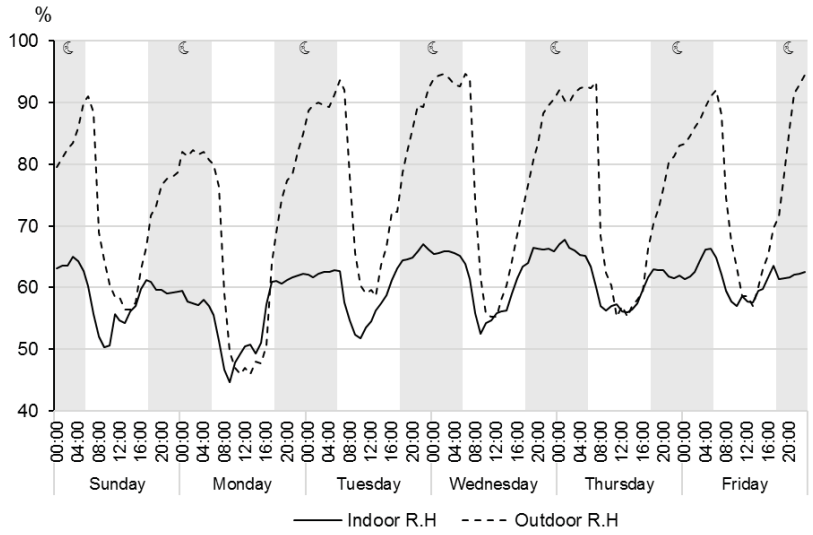


(a)



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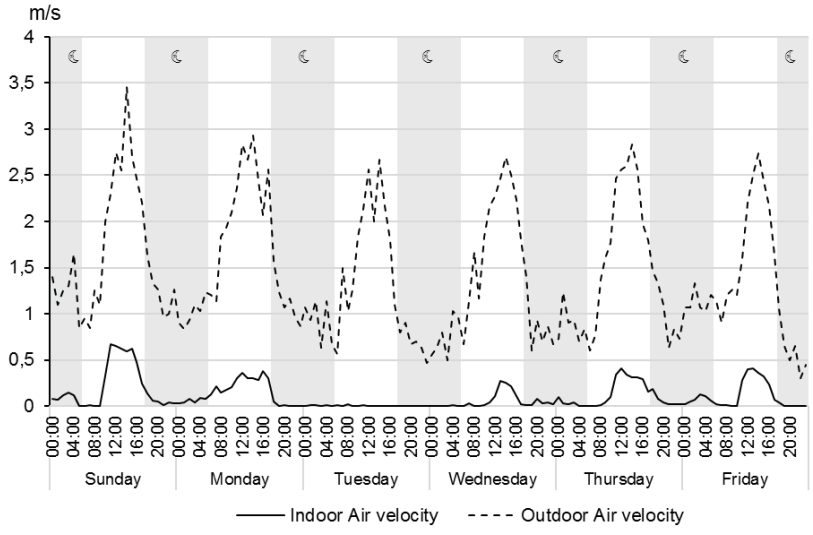

(c)

Figure 4. Hourly means of monitoring of the three balconies over the days of the week, (a) temperature, (b) relative air humidity, (c) wind speed.

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4. CONCLUSION

The present study investigated the interference of the illegal practice of closing the openings of the balconies with glass shutters on the thermal comfort in a residential building in the city of Vitória, ES. The results show that this element is responsible for a heat gain into the environment, bringing thermal discomfort in approximately 80% of the hours of the day during the analysis period, including during the morning, in which the solar radiation is lower, as well as nocturnal periods. Even with the possibility of opening up the glazed openings for residents, there is a sudden reduction of the wind speed within the environment, and this is one of the basic premises of comfort in hot and humid regions. Therefore, it can be inferred that such a practice is not suitable in tropical architectures, and may be more suitable to improve thermal gains and block undesirable winds in cold climate regions.

It is important to emphasize that the balconies monitored had curtains and were directed to Southeast orientation, which assumes that monitoring to be carried out on balconies with other types of guidance and without the presence of curtains can deliver results with temperature means higher than those found and consequently greater thermal load in the environment.

5. ADDITIONAL COMMENTS

The urban concentration of Vitoria is constantly struck by suspended particulates from industrial activities, mainly of two large steel mills located in its vicinity. Such a condition, associated with atmospheric pollution inherent in the ways of large flow of motor vehicles are contributing to the closing of balconies. Thus, the next stage of the research will be conducting air quality monitoring in order to complement the results obtained with the temperature on the balconies to propose guidelines for public policies related to urban and building legislation.

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