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Investigation of the Effects of Glazed Balconies upon Thermal Comfort in Hot Tropical Region

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Abstract: The balcony is responsible to a series of effects on the environmental behavior of a building, mainly in relation of thermal comfort and air distribution to their indoor spaces. Currently a very common practice in several metropolitan areas is the closing with retractable glass panels in balcony openings. This work analyzed the effects of glazed balconies upon thermal comfort in a hot tropical region. Environmental parameters were carried out in a flat alternating the conditions of retractable glass panels to balconies. Thermal simulations were performed considering closing or not the glass door that divides the balcony room; the building material used on the balcony sill; and the use of curtains or shading devices. The results show the maximum mean hourly temperatures recorded on the balcony during the period when the retractable glass panels were closed, reaching peaks between 31.7 and 39.2 °C, above the comfort range recommended by ASHRAE 55. All situations simulated show the thermal discomfort prevails in the use of the closed glass panels reaching DhTD of 94.55 °C/day. Thus, this practice of using most of the closed retractable glass panels in the balconies presents disadvantages and inefficiencies especially in hot and humid tropical climate regions.

Key words: Glazed balconies, thermal comfort, hot tropical region.

1. Introduction

Balconies are an architectural element of unquestionable functional or aesthetic value and have been the object of many studies, mainly with respect to its efficiency to obtain environmental comfort and to improve the quality of the built environment [1]. Ai et al. [2] state that the presence of a balcony in architecture has a series of effects on the environmental behavior of a building, mainly in ventilation and natural illumination; in the effect of shading of facades; in thermal comfort and transport of pollutants. The same authors also affirm that one of the properties of balconies is to improve the uniformity of air distribution in the environment.

In order to improve the usability and functionality of the space, many architects have employed frameless glass windows or glass curtains to balconies, by using sliding or retractable glass panels. The main advantage of the use of glass curtains is the fact that occupants can easily alternate between a fully enclosed balcony, with increased protection from wind, rain, noise and air pollution, or an open configuration with full natural lighting and ventilation. Due to its increasing use, many authors have investigated its effect upon occupants' comfort [3, 4]; however, the studies concerning the impact in hot tropical regions are still scarce [5].

Studies have shown that the temperatures inside the balconies, whose openings have been glazed, are

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almost without exception higher than outdoor air temperature [3, 6, 7]. Hilliaho et al. [8] obtained a mean temperature of 2.0 °C and 5.0 °C higher than outdoor temperature in the field measurements carried out on balconies in Finland without and with retractable glass panels of their openings, respectively. In general, the studies show that these highly glazed spaces perform well compared to the environmental comfort of buildings located in regions of high latitudes [9], probably because they function as a strategy for gaining heat.

Prianto and Depecker [10] found that both balconies and openings play an important role in the modification of indoor velocity and thermal comfort condition. Thus, in order to improve the level of thermal comfort, several studies were developed to study the effect of design parameters on indoor airflow, that is, how changing the position and orientation of the building influences thermal comfort; the size of the windows; the interior compartment; the effects of the presence or lack of the balcony; the shape of the roof; the removal of the building from the street; the format of the building; among others [11, 12].

The objective of this work is to analyze the effects of glazed balconies upon thermal comfort in a hot tropical region. The study is divided into two main parts: (i) a field experiment lasting six weeks by means of indoor measurements of ambient conditions (air temperature, relative air humidity and wind speed) on a balcony and living room of a flat, alternating the conditions of retractable glass panels to balconies; (ii) a computational simulation of the thermal comfort conditions in the study environments considering the weekly alternation of closure of the balcony glazing in the following situations: closing or not the glass door that divides the balcony room; the building material used on the balcony sill; and the use of curtains or shading devices.

2. Methodology

The methodology of this study adopted as a temporal and territorial cut-off the summer period between January and February 2017 in the apartment of a residential condominium in Jardim Camburi, Vitória, ES, Brazil, and was divided into two main stages: (i) a field experiment lasting six weeks by means of indoor measurements of ambient conditions (air temperature, relative air humidity and wind speed) on the balcony and living room of a NE oriented apartment, which is the prevailing wind direction in the city. The selected apartment was monitored by weekly alternating the conditions of glass panels, seeking to verify the influence of the operational circumstances of this device in the thermal comfort of the environment; (ii) computational simulation of the thermal comfort conditions in the study environments considering the weekly alternation of closure of the glass panels in the following situations: closing or not the glass door that divides the balcony room; the building material used on the balcony sill; and the use of curtains or shading devices. These variables sought to evaluate the thermal performance of glazed balconies under different conditions of use and materials used.

2.1 Study Site

The city of Vitória (LAT 20°19'10"S LONG 40°20'16"W) is located in the southeastern Brazilian coast, characterized by a tropical coastal climate with mean temperatures between 18 °C and 26 °C, higher during the summer period, and relative humidity higher than 50%. The prevailing winds of the municipality are NE with a velocity between 2.1 and 3.6 m/s, with S-SE and S-SW winds being considered cold fronts [13]. Vitória is the fourth most populous city of Espírito Santo, with 327,801 inhabitants [14], being part of a geographic area of great urbanization denominated metropolitan area of Grande Vitória. The city has two ports that are part of the largest port complex in Brazil—Porto de Vitória and Porto do Tubarão, as well as several industrial facilities related to mining, pelletizing, stone extraction, cement, and food, and has experienced an intense process of growth in recent years. In fact, the industrial activities of the two major steel mills located in the vicinity of the municipality, associated with soil resuspension, civil construction and vehicular traffic, are the main sources of local air pollution [15]. Thus, the city is experiencing an impasse in the face of the discomfort caused by air pollution, mainly due to vehicular traffic, construction activities and industries. The disturbance caused by dust, particularly by sediment particles, is often the subject of complaints from residents and workers at the local environmental agency. Melo et al. [16] point out the factors that determine the discomfort caused by air pollution in the region, where 86% of those interviewed said they felt uncomfortable in the city and that more than 80% "always" and "often" clean the house for dust removal. It is also important to note that 76.4% of the respondents said they "did not leave the window open" because of the dust. In this way, it can be seen that in order to reduce the amount of dust indoors, passive strategies of environmental comfort lose their place in the practice of closing the building's openings. However, one wonders whether such actions actually contribute to an effective improvement in the salubrity of the space and to the reduction of sedimented dust.

The residential condominium selected for this study is located in Jardim Camburi, strategically close to major vehicular traffic routes and to the main industrial steel center in the region (Fig. 1).

One of the reasons for choosing this building was that it is a residential architectural typology representative of the region studied and also used in a large number of Brazilian cities. The buildings are composed of concrete structures; masonry of perforated ceramic bricks and mortar-coated vibrating concrete blocks; windows and balustrade of balconies

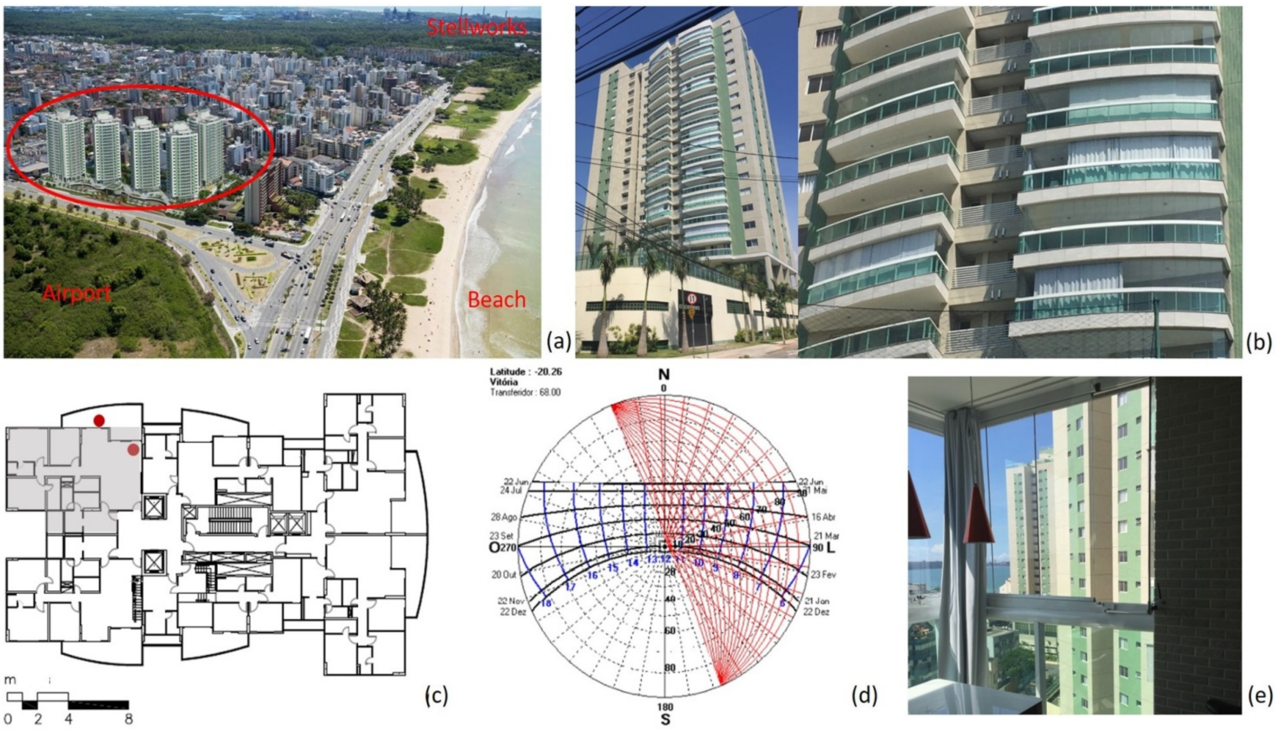

Fig. 1 (a) Bairro Jardim Camburi with emphasis on the residential building used for this study; (b) selected building and type of balconies; (c) floor plan of 10th floor focusing on the monitoring points in the living room and balcony of the apartment; (d) sun path diagram of the city of Vitória, focusing on the orientation of the facade of the study apartment; (e) internal view of the glass closure used to close the balcony opening.

Source: adapted from Ref. [17].

with laminating glass and aluminum frames. The apartment is located on the 10th floor of Torre E, and had the opening of its balcony closed with retractable glass panels of colorless tempered type and 8 mm. The apartment consists of three bedrooms, with approximately 135 m^2 of total area, and the balcony and living room areas of 18.60 and 36.67 m^2, respectively. The living room and the balcony are divided by a masonry wall with a sliding glass door that makes the communication between these environments.

2.2 Sampling Techniques

Regarding closed balconies with retractable glass panels, it is common for users to use a portion of the open panels [4]—mainly due to the thermal discomfort caused when the glazing was completely closed, measurements considering the actual operating conditions of this device were made, namely: (i) three alternating weeks of monitoring maintaining a small opening of the glass panels resulting in 96% of closure, which was called "closed retractable glass panels"; (ii) three alternating weeks of monitoring while keeping the windows fully open, collected on both sides, a situation which was called "open retractable glass panels". The glazing was closed or open every Friday, changing conditions from one week to another.

The environmental parameters were monitored simultaneously on the balcony and in the living room of the apartment. Two data storage devices (HOBO type data loggers U12-013) were used to measure and store air temperature and humidity data. The stored values were transferred to a computer with use of the application software HOBOware (Software for HOBO U-Series Data Loggers & Devices), version 2.7 for Windows. The HOBOs were positioned at approximately 1.10 m from the floor [18] and were properly sheltered, following recommendations of ISO 7726:1998 [19]. Each HOBO was programmed to record information at 1-min intervals. The air temperature and relative humidity of the outdoor air were obtained from the Automatic Weather Station Network of the National Institute of Meteorology, from the automatic station located at the Federal University of Espírito Santo in Goiabeiras, located approximately 4 km from the study region [20]. Measurements of meteorological parameters were carried out simultaneously during the six weeks of indoor monitoring. The 1-min size distributions are used to produce the 1-h and 24-h mean size distributions presented in this study.

2.3 The Thermal Computational Simulation

For the computational simulation of thermal performance, the application software Design Builder, version 3.4.0.041 was used for the computational simulation of thermal performance [21]. In addition to having a user-friendly interface, Design Builder uses the algorithm database from EnergyPlus to perform simulations. The validated climate file with EnergyPlus Weather (EPW)-extension was used [22] corresponding to data compiled during 10 years: from 2000 to 2010. The model was configured according to the original design dimensions and construction materials (Fig. 2). Simulations of 16 situations were performed by alternating the closings of the retractable glass panels from the balcony opening; the closing of the glass door separating the room from the balcony; the building material used on the balcony sill—glazed sill and masonry sill; and the use of curtains or shading devices.

The periods corresponding to the measurements and the values of hourly operating temperatures as output data were simulated, and then subjected to statistical treatments for thermal performance analyses. It is worth mentioning that the simulated apartment corresponded to the same one in which the measurements of temperature, humidity and air quality occurred, noting that due to its intermediate location, the evaluated environment does not suffer direct influence from the thermal gains of the penthouse and the thermal losses by the ground. The physical

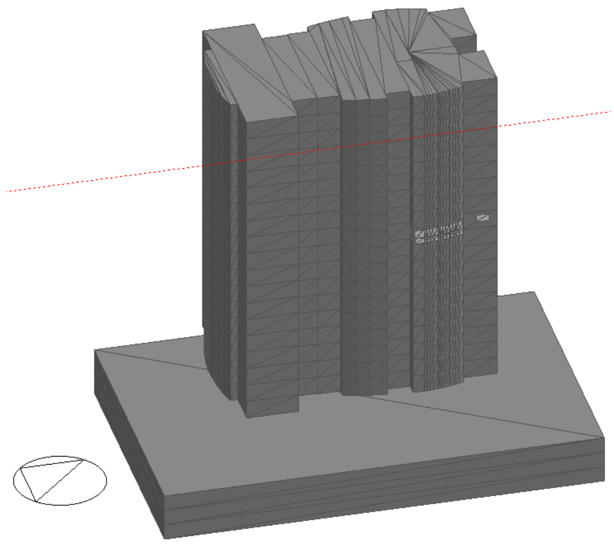

Fig. 2 Computational model of the building.

properties of the building materials and the occupancy of the apartment, as well as the operation of the openings, are described in Table 1.

The first test simulations determined the need for calibration, and the procedure resulted from some minor adjustments in order to obtain the necessary indexes for the validation of the results, as explained below.

2.3.1 Model Calibration

The calibration process corresponded to a detailed adjustment of the building modeling and the configured input data—such as material properties and occupancy patterns—that aimed for the fidelity of the measured data when compared to that measured in the building. For this procedure, we used "uncertainty indexes" and methods to confirm the degree of reliability and results. The Normalized Mean Bias Error (NMBE) and the Coefficient of Variation of the Root Mean Square Error CV (RMSE) methods were used, as they were previously used in similar studies such as that of Saleh [5]. NMBE corresponds to normalization of the Mean Bias Error (MBE) index which is the mean of errors in a sample space. The NMBE scales the MBE data and makes it comparable; however, just as the MBE is subject to cancellation errors, its use alone is not recommended. The CV (RMSE), which measures the variability of errors between measured and simulated values, is not subject to cancellation errors and, because of this, instructions determined by the American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE Guideline 14 [23]), by the International Performance Measurement & Verification Protocol [24] and Federal Energy Management Program criteria [25] from the US Department of Energy were followed, as they recommend using both indexes together in order to verify the accuracy of the model. These indices are calculated by means of mathematical equations in which they relate the measured values to the simulated output data. The NMBE and CV (RMSE) are provided by Eqs. (1) and (2) respectively, $\overline{m}$ corresponding to the mean of the measured values; p the number of adjustable model parameters, which for calibration purposes must be equal to zero; m_i, s_i simulated data and n amount of data measured are the values measured.

$$NMBE = \frac{1}{\overline{m}} x \frac{\sum_{i=1}^{n}(m_i - s_i)}{n-p} x100(\%) \quad (1)$$

$$CV(RMSE) = \frac{1}{\overline{m}} x \sqrt{\frac{\sum_{i=1}^{n}(m_i - s_i)^2}{n-p}} x100(\%) \quad (2)$$

To verify the calibration results, the criteria defined by ASHRAE 14, IPMVP and FEMP were compared with the values obtained by the simulations based on hourly temperatures (Table 2). Two situations in relation to the opening of the balcony glazing were used to calibrate the simulation, that is, for the period between January 14 and 19 (closed balcony) and between January 27 and February 2 (open balcony). After some adjustments in the modeling, both situations presented satisfactory values for the NMBE and CV (RMSE) indices, making the model able to carry out the remaining simulations [26].

Table 1 Material properties and occupancy patterns.

Detailing of the walls and roof with the thermal properties of the materials	
Outdoor walls: masonry with 11 × 14 × 24 cm, 2 cm plaster and 1.5 cm coating (granite in the sill of the balconies and ceramic in the other walls) in the external side, and 1.5 cm plaster in the internal side	16 cm thick
Transmittance (U)	2.79 W/(m^2·K)
Indoor walls: masonry with 9 × 14 × 24 cm bricks, 1.5 cm plaster on both sides and 1.5 cm coating on the sides facing wet areas	12 cm thick (varies according to wet areas)
Transmittance (U)	2.86 W/(m^2·K)
Roof: asbestos cement tiles, with 20 cm air layer and 10 cm slab	-
Transmittance (U)	2.06 W/(m^2·K)
Detailing of the balcony with materials and properties	
Environment area	18.60 m^2
Dimensions of glazed area in guardrail and retractable glass panels	11.60 m × 2.30 m
Ventilation area	6.96 m^2
Fixed laminated green glass guardrail 8 mm thick and glazing in the opening with tempered colorless glass 8 mm thick	Operation configured according to the situations in Item 2.3
Transmittance of 8 mm laminated green glass (U)	5.7 W/(m^2·K)
Transmittance of 8 mm tempered colorless glass (U)	5.7 W/(m^2·K)
*For simulations with variation in the construction material of the balcony, the glass guardrail was replaced with masonry, considering the configuration of outdoor walls of the building.	
Human parameters and occupancy of the building	
Users	7 a.m.-6 p.m. = 25% occupied
	6 p.m.-10 p.m. = 50% occupied
	10 p.m.-7 a.m. = 100% occupied
Clothing	Summer = 0.50 clo
Metabolism: slight walking activity	90 W/person
Pattern of occupation	8 people

Source: adapted from [27, 28].

Table 2 Hourly calibration criteria for NMBE and CV (RMSE) recommended by ASHRAE 14, IPMVP and FEMP compared to the values calculated based on the results of the one-week simulation for scenarios closed balcony and open balcony.

	Hourly calibration criteria for NMBE (%)	Hourly calibration criteria for CV (RMSE) (%)
ASHRAE	+/- 10	30
FEMP	+/- 10	30
IPMVP	+/- 5	20
	Simulation results for NMBE (%)	Simulation results for CV (RMSE) (%)
Closed balcony	0.65	7.78
Open balcony	0.51	6.63

Source: adapted from ASHRAE 14 [23-25].

2.3.2 Analysis of the Results for the Thermal Performance Simulations

The main factors of thermal performance analysis were the hourly operating temperature and comfort temperature, as defined in the adaptive comfort chart of ASHRAE 55 [29], which uses the variation in mean monthly outdoor temperature and the percentage of acceptability ranging from 80% to 90% for determining the maximum and minimum values of comfort temperature. Candido and De Dear [30] argue that the adaptive thermal comfort model offers a new approach to naturally ventilated buildings by defining that temperature fluctuations can be seen as acceptable to their occupants. This approach strengthens the adoption of naturally ventilated spaces as one of the strategies for the conservation of resources, contributing to the construction of buildings increasingly integrated with the environment in which they are inserted. In this case, a level of 90% acceptability was adopted, given that the months in which measurements and the simulations were taken correspond to the summer period, the most critical season for heat. The choice of 90% user acceptance percentage reinforces the concern with the project design of the current buildings and their components. ASHRAE 55 also proposes the use of the 90% percentage as requirement in order to acquire a higher standard of thermal comfort. Thus, taking into account the definition of comfort temperatures, the thermal performance evaluation of simulated environments was based on indicators in accordance with the statistical approach to thermal comfort proposed by Sicurella, Evola and Wurtz [31] and adapted in other Brazilian studies by Nico-Rodrigues et al. [32], who analyzed changes in operating temperatures during the 24 hours of the day.

The method of analysis relates two indicators: Thermal Discomfort Frequency (TDF) and Degrees-hours of Thermal Discomfort (DhTD). The TDF corresponds to the percentage of time (full hour) in which the operating temperature was above the comfort temperature, wherein a day corresponds to 100% and each hour to 4.17%. The DhTD is determined by the daily sum of the difference between operating temperature and comfort temperature, when operating temperature assumes values higher than comfort. The maximum reference value used for the DhTD was the highest found among the simulated situations. These indicators are connected by means of a buoyancy diagram (Fig. 3) that relates the data to a scatter plot and sets four zones, whose frequency and intensity of discomfort vary between frequent or temporary and light or intense, wherein the best scenario is the one that converges to the origin.

3. Results and Discussion

The results were divided into two sections: (i) thermal comfort—field experiment; (ii) thermal comfort—computational simulation.

3.1 Thermal Comfort—Field Experiment

The results of the measurements of environmental parameters in the balcony show mean values of 1 minute for temperatures of 29.9 ± 0.9 °C and 27.8 ± 1.0 °C; relative humidity of 65.2 ± 3.0% and 72.5 ± 4.4% and wind speed of 0.1 ± 0.1 m/s and 0.6 ± 0.2 m/s for the balcony with the glazing scenario under the pattern closed retractable glass panels and open retractable glass panels, respectively. For all monitored meteorological parameters, a significant difference was observed between the measurements of the open and closed retractable glass panels (Mann-Whitney test p = 0.000), showing changes in the microclimate of the environment due to this action. To calculate thermal comfort range in naturally ventilated environments, the adaptive comfort methodology was used, which adopts the variation in mean monthly outdoor temperature and the percentage of acceptability for determining maximum and minimum comfort temperature values, as suggested by ASHRAE 55 [29]. The mean monthly outdoor temperature obtained from the measurement period was inserted into the adaptive comfort graph [29], resulting in the comfort temperature range for the period in question, considering a value of 90% of acceptability. The choice of user acceptance percentage of 90% is justified for the city of Vitória, whose predominant wind action significantly interferes with the ease of adaptation by the user to temperature variations [32]. The calculations and temperature range found are presented in Table 3.

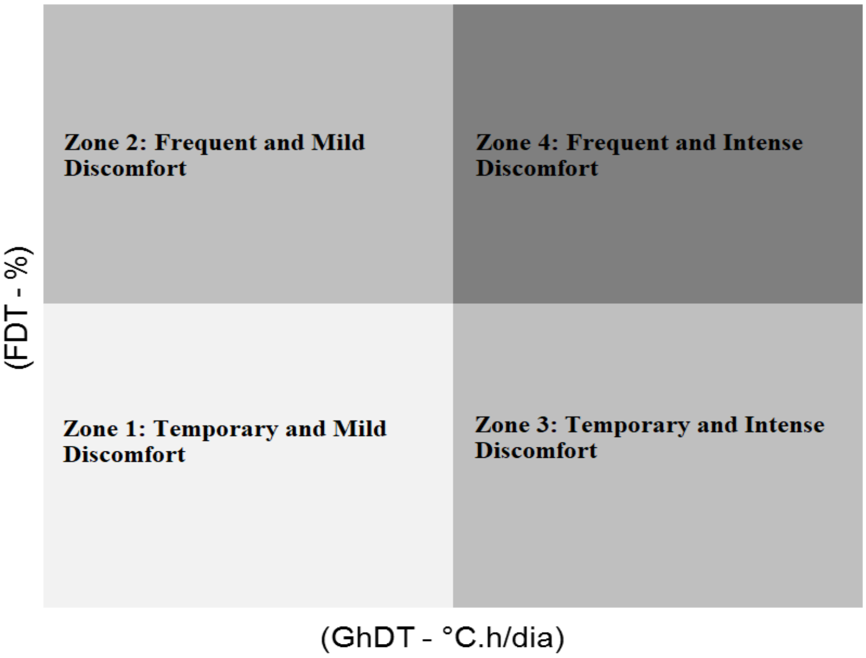

Fig. 3 Buoyancy diagram.

Source: adapted from Ref. [31].

Table 3 Mean outdoor temperature values during the period and comfort temperature.

Period	Mean outdoor air temperature during the study period (°C)	Neutral temperature (°C) $Tn = 0.31\ (Te) + 17.8$	Comfort temperature range (°C) ASHRAE 55 90% acceptability
14/01 up to 24/02	26.8	26.10	23.60-26.60

Fig. 4 shows the hourly mean air temperature and humidity for each day of the week in the balcony and living room environments, considering the three-week monitoring data set with the same closing pattern of the balcony glazing. The results were compared with the external data and calculated comfort zone was calculated. Indoor environments tend to follow the seasonality of outdoor temperature, both for scenarios with open and closed retractable glass panels. However, it is worth mentioning that when the glazing was open, the temperature on the balcony was very close to the outdoor temperature recorded in the morning, between 4:00 and 7:00 a.m., with the lowest mean temperatures, varying from 25 °C to 25.7 °C, which does not happen with the living room, which presented mean temperature values between 27.1 °C and 29.4 °C for the same period. This may be associated with the glass door that separates the balcony from the living room, which is closed most of the time due to local dust, meaning that this environment does not benefit from the ventilation provided by the balcony openings, in addition to the retention of heat by the material used in the closing of the door. Temperatures increase in the morning, around 8:00 a.m., mainly due to the

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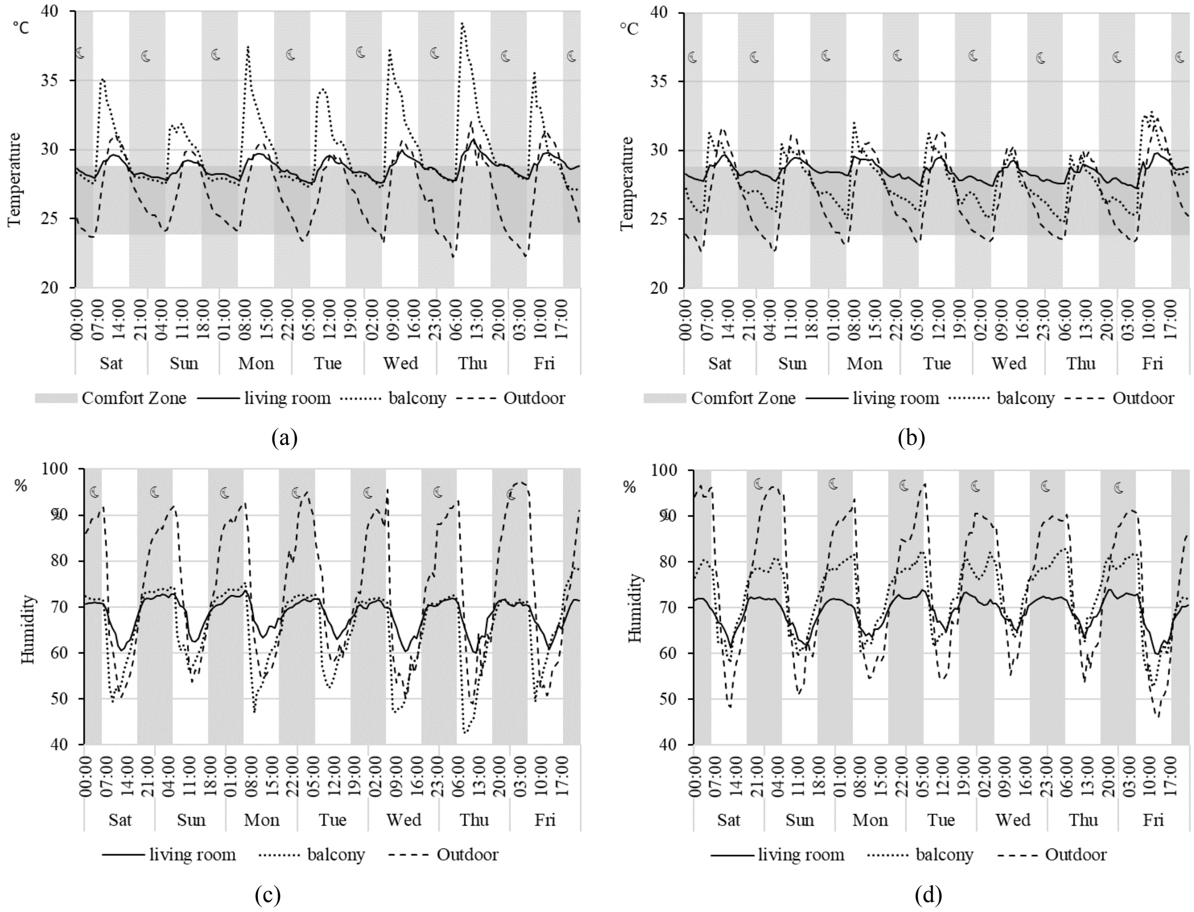


Fig. 4 Hourly mean temperature values for (a) closed retractable glass panels and (b) open retractable glass panels, and hourly mean air humidity for (c) closed retractable glass panels and (d) open retractable glass panels, for each day of the week, considering a mean of three weeks for monitoring in each opening scenario for the balcony glazing for both the living room and balcony environments.

predominantly NE orientation of the balcony, reaching the highest mean hourly temperature of 32.8 °C.

When the retractable glass panels were closed, mean room temperature performed similarly to the situation where the retractable glass panels were open, presuming that even with the benefits of natural ventilation, keeping the dividing door closed between the environments makes the room environment not benefit significantly from the strategy of passive thermal conditioning due to local dust. It should be noted that the mean maximum hourly temperatures recorded on the balcony during the period when the retractable glass panels were closed reached peaks between 31.7 °C and 39.2 °C at 8:00 a.m., resulting in values higher than the comfort range recommended by ASHRAE 55, whose maximum calculated value was 28.84 °C.

As can be observed in Figs. 4c and 4d, the city of Vitória presents high rates of relative humidity, with the outdoor environment reaching mean values over 90% in the night period. The results of the monitoring showed that in the scenario of open retractable glass panels, the mean relative air humidity for the three weeks of the experiment was 72% on the balcony, being closer to the mean of the same monitoring period of relative humidity (75%) than that recorded for the closed retractable glass panel scenario, which was 65%. The maximum indoor values were recorded during the morning, in the range between 76.2% and 82.3%, and the mean minimum value was 57% at 1:00 p.m. However, when the retractable glass panels were closed, the mean relative humidity of the balcony suffered a smaller amplitude of variation, very closely following the values recorded in the living room, reaching mean values around 9:00 a.m. (42.5% to 49.5%), which shows the influence of glass in reducing the rate of relative humidity and consequently the impact of built environmental conditions in hot and humid tropical climates.

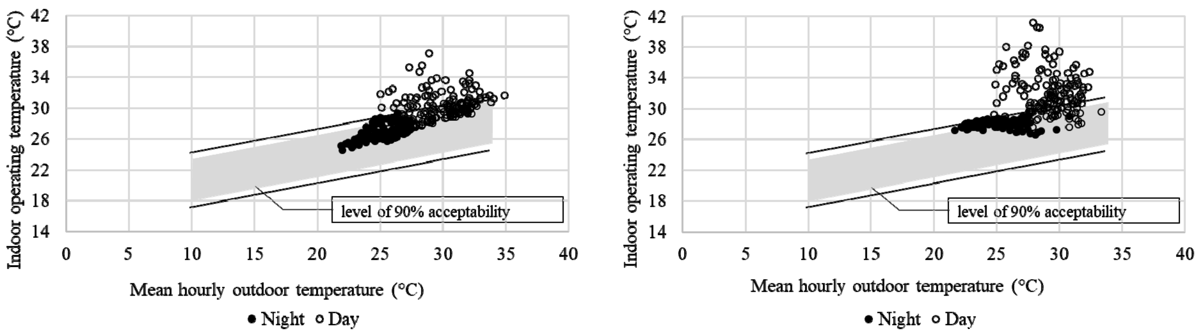
The hourly operating temperatures resulting from measurements of the experimental campaign on the balcony of Tower E, in the open and closed retractable glass panels scenario while distinguishing the fluctuations of values during day and night were plotted on the ASHRAE 55 model, as shown in Fig. 5.

The range of temperatures outside the acceptable range for occupants during the day can be observed, especially when retractable glass panels were closed. Therefore, the use of closed retractable glass panels in the balconies, for the most part, significantly interferes with the increase in indoor air temperature of the environment, such that a certain orientation, even if favorable with respect to bioclimatic architecture, may become thermally uncomfortable.

3.2 Thermal Comfort—Computational Simulation

The comfort temperature values for the evaluation of thermal comfort in ventilated environments were defined by the methodology that adopts the variation in mean monthly outdoor temperature and a percentage of acceptability of 90% for the determination of maximum values, as suggested by ASHRAE 55 [29]. The mean monthly outdoor temperature obtained for January and February according to the conducted simulation was inserted into the adaptive comfort formula [29], obtaining the maximum comfort temperature values for the period in question. After applying the calculation method defined by ASHRAE 55 [29], the temperature values of 28.45 °C for January and 28.27 °C for February were obtained.

In order to evaluate environmental thermal performance while considering the same days the measurements occurred indicators based on the statistical approach for thermal comfort were used as proposed by Nico-Rodrigues et al. [32], in which changes in the operating temperature were analyzed during the 24 hours of the day. In order to analyze thermal comfort conditions by means of buoyancy graph it was necessary to define the daily reference DhTD, obtained by means of the highest sum of daily DhTD after simulation of the same measured days, resulting in the reference DhTD. The maximum TDF reference value for all situations was 100% or 480 h = 20 simulated days (three weeks); and the DhTD for the established period was closed retractable glass panels = 94.55 °C/day, and open retractable glass panels = 39.15 °C/day, considering all combinations of variables—open or closed door; masonry or glass sill; shading devices or curtain.



(a) (b)

Fig. 5 Hourly operating temperatures of the balcony on Tower E plotted with the model by ASHRAE 55 in the scenarios (a) open retractable glass panels and (b) closed retractable glass panels.

Source: adapted from ASHRAE 55 [29].

The results were evaluated with regard to three levels of discomfort: (i) intense and frequent discomfort, showing high values of DhTD and TDF in a greater number of hours and in more than 50% of the days analyzed; (ii) days with mild but frequent discomfort, setting temperatures above the comfort temperature reference for a longer period in the day, shown by TDF with high percentages; and (iii) mild and temporary discomfort, highlighting days with temperatures above that defined for comfort during some hours of the day. It can be observed that the data obtained with the use of closed retractable glass panels resulted in an uncomfortable environment, due to its high values of TDF and DhTD (Figs. 6 and 7).

Analysis of the sum of TDF and DhTD for the situations defined for the balcony showed that the adoption of components—shaders, alternating sill material, opening of the glazing, as well as opening or not the communication port of the balcony with the room, resulted in an operating temperature with values still high, culminating in the increase of the indicator values.

In the scenario involving a fully open balcony, the room had two levels of discomfort: days with mild and temporary discomfort, setting temperatures above the comfort reference for a shorter period on the day, as demonstrated by TDF with low percentages; and intense and temporary discomfort, specifically days with high temperatures for some hours of the day in all situations analyzed (Figs. 8 and 9).

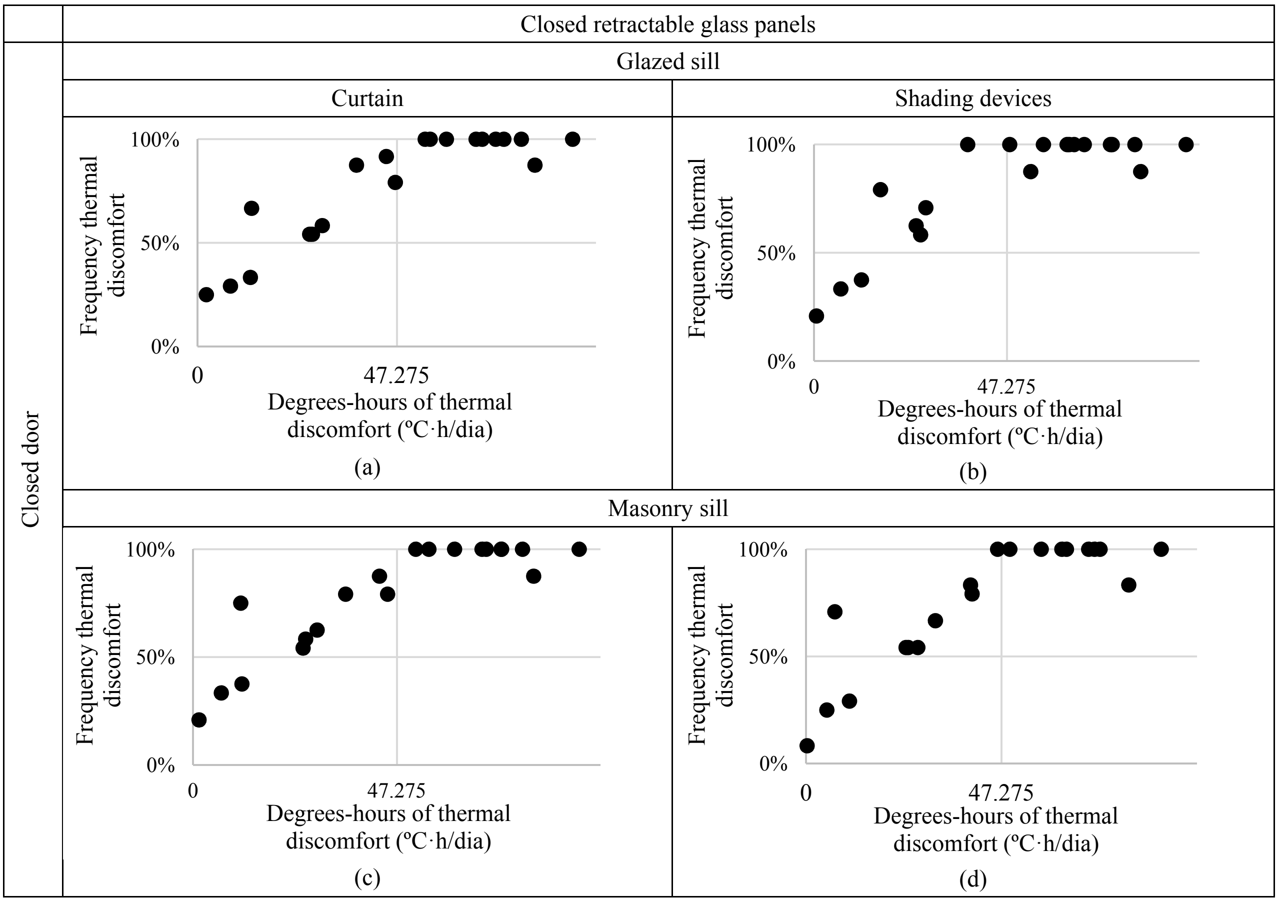


Fig. 6 TDF and DhTD values obtained with respect to the three-week simulation relative to the study period, considering a scenario with closed retractable glass panels and closed balcony door, with the following situations varying: (a) glass sill and use of indoor curtain, (b) glass sill and outdoor shading device, (c) masonry sill and use of indoor curtain and (d) masonry sill and use of outdoor shading device.

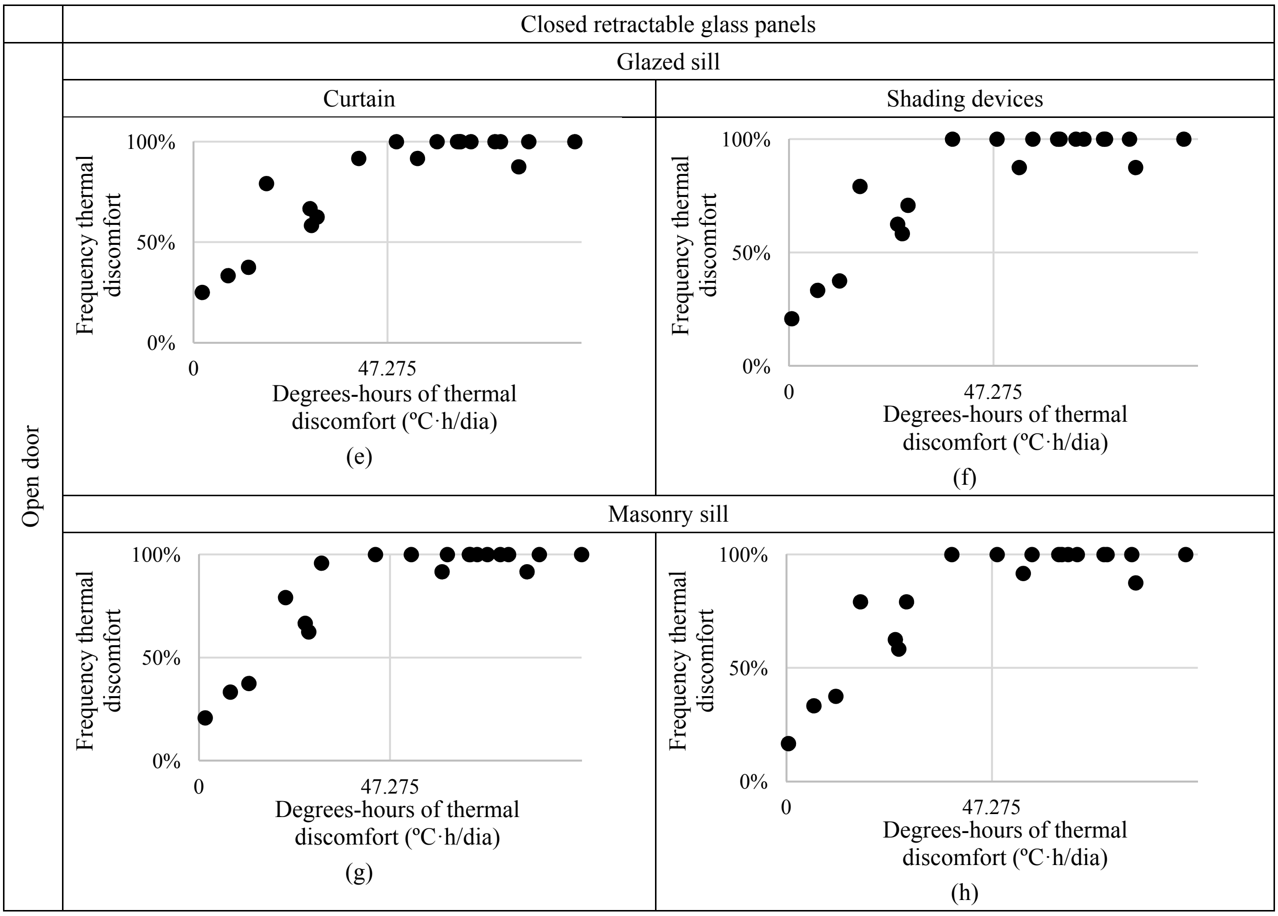


Fig. 7 TDF and DhTD values obtained with respect to the three-week simulation relative to the study period, considering a scenario with closed retractable glass panels and open balcony door, with the following situations varying: (a) glass sill and use of indoor curtain, (b) glass sill and outdoor shading devices, (c) masonry sill use of indoor curtain and (d) masonry sill and use of outdoor shading devices.

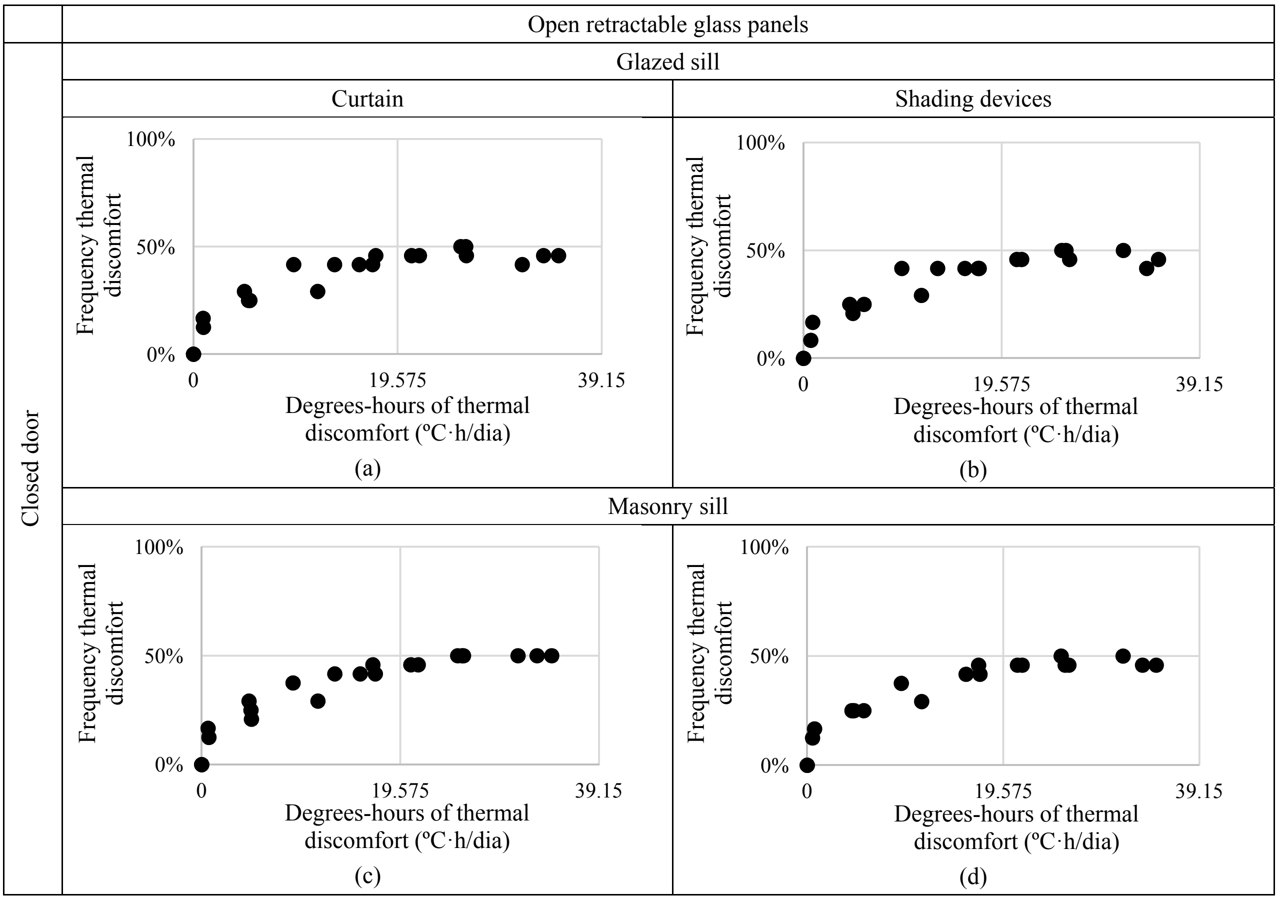


Fig. 8 TDF and DhTD values obtained with respect to the three-week simulation relative to the study period, considering a scenario with open retractable glass panels and closed balcony door, with the following situations varying: (a) glass sill and use of indoor curtain, (b) glass sill and outdoor shading devices, (c) masonry sill and use of indoor curtain and (d) masonry sill and use of outdoor shading devices.

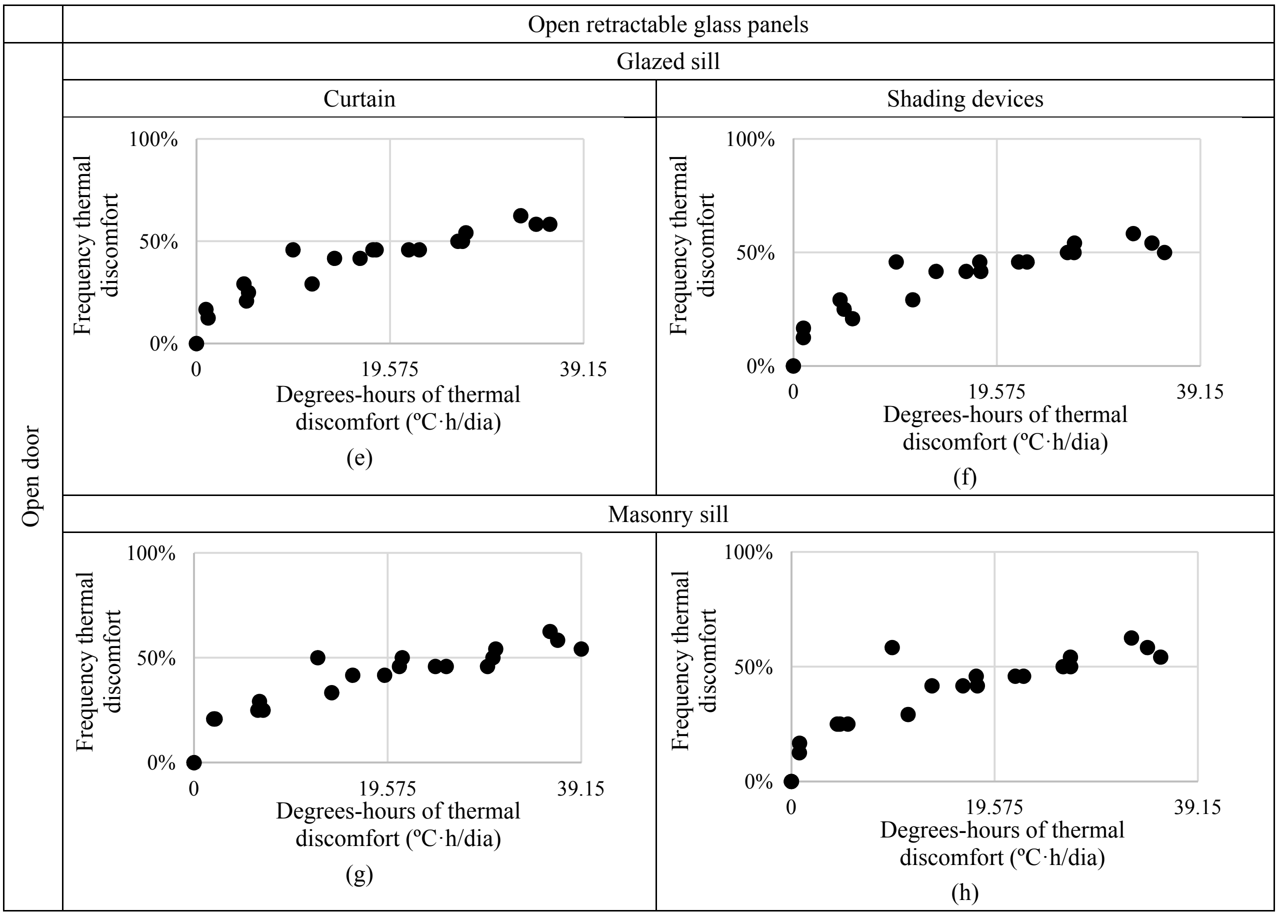


Fig. 9 TDF and DhTD values obtained with respect to the three-week simulation relative to the study period, considering a scenario with open retractable glass panels and open balcony door, with the following situations varying: (a) glass frame and use of indoor curtain, (b) glass frame and outdoor shading devices, (c) masonry frame and use of indoor curtain and (d) masonry frame and use of outdoor shading devices.

It should be noted that the balcony with closed retractable glass panels led to results by means of the sum of DhTD, with temperatures higher than the simulations with open retractable glass panels, equivalent to a difference of approximately 60% (Fig. 10). When the door separating the balcony and the room was open, conditions were a bit better for the closed door when compared to the open door scenario. In the scenario with open door, heat dissipation occurred faster, given the size of the environment and the type of sill material. For the open door scenario, the heat absorbed by the balcony was irradiated into the room and resulted in a high indoor temperature, recording a higher DhTD.

For the result obtained in the TDF sum (Fig. 11), it could be observed that the balcony scenarios remained similar to that obtained by the sum of DhTD, considering the balcony with closed retractable glass panels and open door with a higher percentage of discomfort than with the door closed, due to the same reason explained for the DhTD.

The best thermal condition in the balcony scenario with closed retractable glass panels was that with the door that separates the balcony from the closed room in the combination of masonry sill and outdoor shade. As for the situation of the balcony glazing, the best results also occurred with the communication port of the balcony with closed room and shading devices, but with glass sill. It should be noted that the thermal transmittance of masonry is much smaller than that of

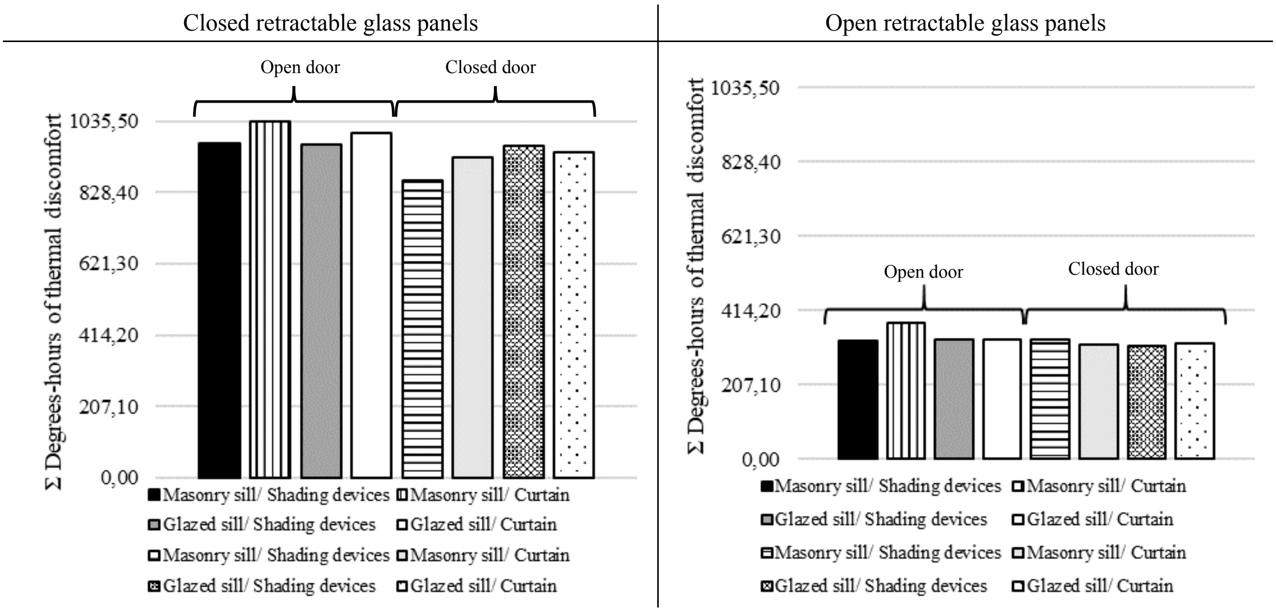


Fig. 10 Sum of DhTD (°C·h/day) throughout the period.

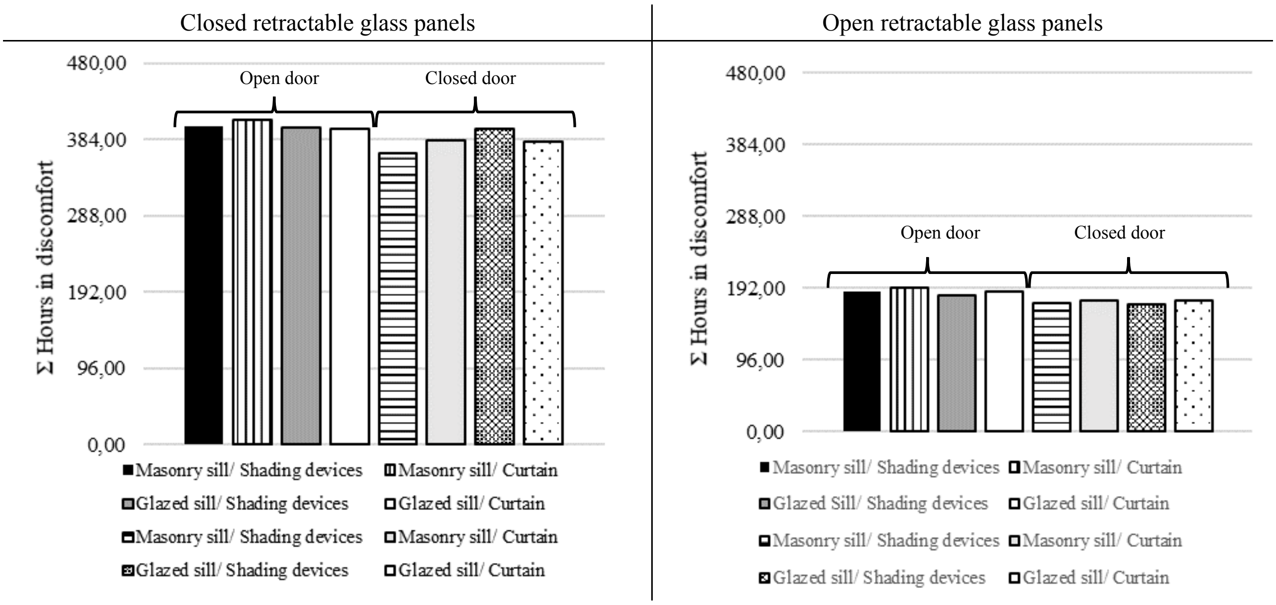


Fig. 11 TDF sum (hours of discomfort = *h*) throughout the period.

glass, thus resulting in the difference observed in the situations described above. The action of natural ventilation on the condition of the balcony with open retractable glass panels and with glass sill was effective in terms of thermal exchange by means of permanent ventilation, since the thermal resistance of the glass is much weaker and its transfer into the medium is faster. The situations analyzed in this case study demonstrated that the adoption of shader, permanent ventilation and alternating material on the sill are important conditions for achieving the best combination of architectural elements that result in the best thermal performance in buildings.

4. Conclusion

This study investigated the interference in thermal comfort of the practice of closing balcony openings with retractable glass panels, having as case study a building located in the city of Vitória, Brazil. The glazed balcony is becoming a common practice in buildings around the world, especially considering the need to reduce noise and sedimented dust inside their homes. However, from an energy point of view, this practice presents disadvantages and inefficiencies especially in hot and humid tropical climates.

It can be clearly seen from the results of the environmental parameters monitoring in the study apartment that the adoption of balcony with closed retractable glass panels most of the time causes a significant change in the microclimate condition of the monitored environment by increasing indoor air temperature, decrease in the relative air humidity as well as the rate of ventilation. This can be demonstrated by the fact that when the retractable glass panels are open, the indoor air temperature of the balcony approaches outdoor air temperature, guaranteeing more hours within the indicated comfort zone, which reinforces the importance of natural ventilation as a strategy for passive thermal conditioning in hot and humid tropical climates. Even in the case of a favorable orientation, the maximum mean hourly temperatures recorded on the balcony during the period when the retractable glass panels were closed, reach peaks between 31.7 °C and 39.2 °C at 8:00 a.m., well above the comfort range recommended by ASHRAE 55 whose maximum calculated value was 28.84 °C, often making residents resort to artificial air conditioning solutions to remedy the thermal discomfort of the environment.

The results of the thermal performance simulation reinforce the aspect related to thermal discomfort caused by glazing in balcony openings, reaching a DhTD of 94.55 °C/day for the closed retractable glass panels scenario and 39.15 °C/day for the open retractable glass panels scenario. Verification of other balcony use situations such as opening the balcony door and using curtains or shading devices as well as the use of masonry on the balcony sill shows that thermal discomfort prevails in the use of most closed glazing balcony in all scenarios. The best thermal condition in the balcony scenario with closed retractable glass panels occurred with the door that separates the balcony from the closed room in the combination of masonry sill and outdoor shading devices.

In summary, it can be said that the practice of using the closed retractable glass panels in the balcony interferes negatively in thermal load of apartments located in hot and humid tropical climates, mainly due to the reduction in the natural ventilation rate in the environment. This fact shows that, in general, current residential buildings are not presenting efficient envelopes with regard to comfort and energy efficiency. Given this context, the expansion of research related to the theme is of utmost importance, both for the use of results in the project process as well as to make consumers—future building users—aware of the properties that effectively allow a better comfort condition with the least energy expenditure.

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