CADERNOS
PROARQ 30

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Analysis of surrounding urban shadings on an insulated building in a hot and cold Brazilian climates

Análise do sombreamento do entorno em uma edificação residencial isolada em climas quente e frio do Brasil

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Resumo

A análise da influência do sombreamento em edificações residenciais não é algo novo. As discussões sobre desempenho termoenergético das edificações, de uma forma geral, consideram os limites de transmitância térmica definidos pela NBR 15575 (2013) e NBR 15220 (2005), as quais não caracterizam um envelope com elevado nível de isolamento térmico. Considerando que o edifício é um sistema e que os elementos opacos e transparentes do envelope impactam seu desempenho termoenergético , a análise da influência do sombreamento do entorno em edifícios residenciais com elevado nível de isolamento térmico passa a ser relevante. O objetivo deste estudo é avaliar a influência do sombreamento do entorno em uma edificação unifamiliar com elevado nível de isolamento térmico, atendendo ao conceito do Standard Passive House. O estudo foi realizado para os climas extremos de frio e calor, representados pelas Zonas Bioclimáticas Brasileiras (ZBB) 1 e 8, respectivamente. Foram realizadas simulações computacionais no software DesignBuilder, que apresenta interface gráfica para o EnergyPlus. Oito diferentes cenários de sombreamento foram testados. Os resultados evidenciaram a relação entre sombreamento da edificação e incremento na eficiência termoenergética. Os níveis ideais de sombreamento, no entanto, variaram. Para o clima quente (ZBB8) o melhor desempenho foi obtido com o maior nível de sombreamento (aplicado a paredes externas e cobertura), confirmando a estretégia bioclimática indicada esta ZBB. Diferentemente, para o clima mais frio (ZBB1), o melhor desempenho foi obtido com um nível menor de sombreamento, incidindo apenas nas paredes externas.

Palavras-chave: Sombreamento. Eficiência Energética. Simulação Computacional. Conforto Térmico.

Abstract

The analysis of the shading influence on residential buildings is not new. Discussions about building's thermal performance, in general, consider the thermal transmittance limits defined by NBR 15575 (2013) and NBR 15220 (2005), which do not characterize na envelope with a high level of termal insulation. Considering that the building is a system and the opaque and transparent elements impact on its termal-energetic performance, the analysis of the surrounding shadings on residential buildings with a high insulation level becomes relevant. The objective of this study is to evaluate the influence of the surrounding shadings on a single-family building with a high level of thermal insulation, taking into account the Passive House Standard. The study was conducted to the extreme cold and warm climates, represented by the Brazilian climate zones (ZBB) 1 and 8, respectivelly. Computer simulations were performed in the software DesignBuilder, that has a graphic interface for EnergyPlus. Eight diferent scenarios of shadowing were tested. Results pointed out the relationship between the building shadowing and the increasing in termo-energetic performance. The ideal levels of shadowing, thus, varied. For the warmer climate (ZBB8), the best performance was obtained with the higher level of shadowing (applied to the external walls and roof), confirming the climate-responsive design strategy fairly indicated to that ZBB. Conversely, for the colder climate (ZBB1), the best performance was achieved with a lower level of shadowing, including only the external walls.

Keywords: *Shading. Energy Efficiency. Computer Simulation. Thermal Comfort.*

Introduction

One of the main problems humankind faces today is the high demand for natural resources. Several countries have been searching for alternative means to meet their survival needs, minimising the use of these resources. In such a context, passive energy efficiency strategies emerge. Concerned with these issues, the European Union has published Directive 2010/31/EU, setting targets for the Member States to achieve and meet by 2020, regarding new constructions, which are intended to be buildings with almost zero energy consumption (Nearly-Zero Energy Buildings - NZEB) (EPBD, 2010). The idea is that these buildings have in their genesis energy efficiency measures that passively reduce energy consumption needs related to their use and operation (RUZICKI et al., 2016).

Initiatives aiming to increase building energy efficiency levels have been implemented in Brazil in recent years. In particular, the energy efficiency regulations RTQ-C (Technical Requirements for the Quality of the Energy Efficiency Level of Commercial, Public and Services Buildings) and RTQ-R (Technical Requirements for the Quality of the Energy Efficiency Level of Residential Buildings), and the thermal performance standards of buildings NBR 15220 and NBR 15575 (RUZICKI et al., 2016).

The usually unplanned process of urbanisation and rapid densification of cities tend to generate territorial occupation that ends up extinguishing desirable characteristics of the local environment. One of the causes for high consumption of electric energy is the verticalization of urban meshes. Without proper urban planning, that verticalization creates sites with continuous shading, bringing a high use of electrical equipment to increase the indoor thermal comfort (especially in colder climates).

Tree shading influences the energy performance of buildings. A study published by Duarte et al. (2012) presents tree shading contribution to the reduction of average radiant temperature, causing less absorption and transfer of energy to the environment's interior, thus improving the conditions of thermal comfort. The study was carried out in school buildings, in the Brazilian city of Cuiabá, Mato Grosso. The method consisted of experimental study observing the thermo-hygrometric variables through computational simulations. Close classrooms of same architectural design, construction materials and orientation were analysed, with differences arising exclusively from tree shading. Results indicated a difference of 2°C in internal temperature between the rooms without any shading and the ones with four facades shaded, these deployed in the east-west direction. The shaded North-South oriented room presented internal temperature 1.57°C lower than the room with no shading. That difference generated about 18 to 50% in reduction of annual energy demand for artificial climatisation of the building. Besides, that study indicated that the tree shading also contributed to evaporative cooling and humidification, increasing its benefits to the environment's microclimate.

Littlefair et al. (2010) evaluated different shading devices for different UK offices, such as externally fixed brises, manually controlled internal blinds and external and internal blinds driven through automation.

Salazar (2007) discusses, in his work, different qualitative comparisons between several alternatives of shading, allowing a quick and precise choice of an adequate solution. For the context of this work, such an evaluation is interesting in the proper choice of the proposed device.

Olbina and Beliveau (2009) address the theme of transparent shading devices, regarding the choice of opaque or translucent materials. The objective was to create a new design of transparent curtains, with better natural lighting performance. The study proceeds to the application of a triangular cross-section for slats and the use of transparent plastic and silver reflective film as materials for new consumers, following the principles of optics, considering a case study with new transparent curtains, such as the commercially available opaque ones. The transparent curtains presented the best result in the proposed shading device, opening new possibilities of discussion on the subject.

This study has as primary objective the evaluation of the impact of surrounding shadings in a building with high level of thermal insulation. Evaluation indicators such as levels of internal environment thermal comfort, adaptive comfort, as well as building's energy consumption are observed, with the building being artificially heated and cooled. A quantitative analysis was made, by comparing results obtained in two diferent Brazilian climates were compared. The projects in the two climates (colder and warmer) had the same architectural design, with the same variables being analysed.

Method

The method used to perform the work is based on RUZICKI et al. (2016), and is divided into five stages: 1) definition of the research hypothesis; 2) simulation and classification of the energy efficiency according to the RTQ-R levels; 3) modelling the environment and analysing the shadow trace; 4) simulation of the energetic thermal performance of the residence; and 5) analysis and discussion of results.

Stage one - Definition of the research hypothesis

This work seeks to confirm the hypothesis that greater shading incidence in a building with a high level of thermal insulation can increase its thermal-energetic performance.

Stage two - simulation and classification of the energy efficiency according to the RTQ-R levels

The evaluation of the buildin energy efficiency was carried out for the summer and winter, according to RTQ-R. The analysis is presented in two parts: firstly, the architectural design and the building envelope are characterised; secondly, the building modelling and configuration according to the RTQ-R parameters are described.

Architectural design

Based on the passive strategies presented by Pouey (2011), and according to the premises of the Passive House concept, Dalbem et al. (2015) developed and published the architectural design of a highly insulated building, on which this study is based. The project represents a single-family residence [1], with a total area of 126.45 m², distributed on 2 floors, with a garage for one car, an integrated kitchen and living room, a solarium, two bedrooms and a bathroom on the ground floor, and the work area, technical area and another bathroom on the second.

A design strategy was defined to avoid the entrance of solar radiation in the summer and to allow it in the winter, considering the building characteristics. For that reason, it was prioritised to have the largest façade to the north, thus increasing the solar radiation gains during winter. This façade is also the one with the highest percentage of openings, and where the solarium is located, with translucent openings and walls, which have elements of solar protection as other window frames, and during the summer period reducing undesirable gains, with the smaller façades facing east and west [2].

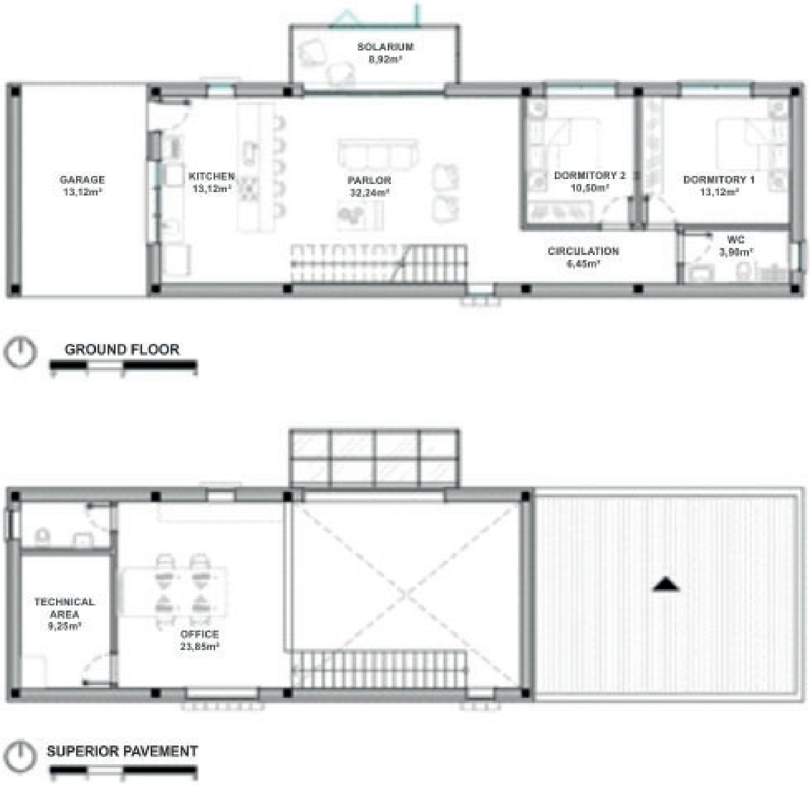


FIGURE 1- Architectural design, ground floor and upper floor plans, 2015.

Source: Dalbem et. al. (2015, p.5).

FIGURE 2 - Longitudinal section of the building, 2015.

Source: Dalbem et. al. (2015, p.5).

	Total	North	East	South	West
Gross Wall Area (m2)	219.95	68.64	32.98	85.35	32.98
Window Opening Area (m2)	29.83	22.79	0.48	6.08	0.48
Opening Percentage – frames (%)	13.56	32.20	1.46	7.12	1.46

Building Envelope Characteristics

Figures [3], [4], [5] and [6] present the main characteristics of the building envelope, as the total thermal transmittance of each element of the construction, which takes into account the internal and external surface resistances according to NBR 15220 (ABNT, 2005). The constructive elements used in the project are following the Passive-On requirements (PASSIVE-ON PROJECT, 2007).

The Passive-On Project defines, among others, the thermal characteristics for climates with distinct climatic seasons, with a high thermal amplitude throughout the day. For that type of climate, the thermal transmittance of the opaque elements in the building envelope defined as the ideal is of approximately 0.30 [W / (m².K)].

Configuration of simulations according to the RTQ-R parameters

In order to evaluate the energy efficiency of the highly insulated building envelope in the Brazilian climatic zones 1 and 8, simulations were performed in the software DesignBuilder version 3.4.0.041. The envelope parameters were kept the same for both climatic zones. However, the site configurations, such as the weather file and the average soil temperature, were used according to the studied area.

Considering the average values of the internal and external temperatures of the building, and following the RTQ-R requirements, the average soil temperature was calculated through the use of the Slab device, linked to Energy Plus. In the project, 3mm double glass frames were used, with a 13mm air chamber, the solar heat gain coefficient (SHGC) of 0.69 and thermal transmittance (U) of 1.96 [W / (m².K)]. The PVC white frame has thermal transmittance (Chase) of 3.633 [W / (m².K)].

Considering that according to the RTQ-R only the environments with high occupancy are evaluated, the environments analysed in this study were the two bedrooms, the living room combined with the kitchen, and the office. The use and occupancy patterns, the internal load density for equipment and the lighting power density of the extended dwelling environments, presented in [9], were set according to the RTQ-R parameters. From the values recommended by the RTQ-R, which defines two people per dormitory and the room and the office occupied by all users at the same time, the occupation rates of the building were determined.

Analyzing the energy efficiency of the envelope of autonomous housing units (UH) and single-family buildings through the prescriptive method, equations are used according to the climatic zone, or through thermo-energetic simulation (INMETRO, 2010). The model was divided in naturally ventilated from 9:00h to 8:59 p.m. and artificially heated from 9:00 p.m. to 08:59 a.m., because according to RTQ-R, to evaluate the level of envelope performance, these two situations should be simulated and then compared with the reference values of the classification tables of the energetic efficiency levels of the envelope.

In the evaluation of the summer period, the data obtained in the simulation of the naturally ventilated building is used, where the 8,760 hours of the year are evaluated for each extended dwelling environment, in order to obtain the degree-hour indicators of temperature cooling, which has a base temperature of 26ºC according to Equation 1.

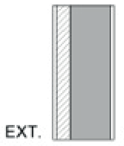
$$GH_R=\Sigma(T_0-26^{\circ}C) \qquad \text{Equation 1}$$

Where:

GH_R: degree-hour indicator for cooling;

T_0: hourly operative temperature (ºC).

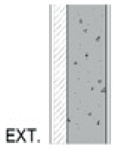
Figures [7] and [8] show the efficiency levels for each weather file used and the degree-hour limits for each level. The degree-hour indicators obtained in the equation must be equal to or smaller than the indicated values. The relative numeric equivalent of each extended residence environment was calculated for heating ($EqNumEnvAmb_A$) and cooling ($EqNumEnvAmb_A$). The relative consumption for heating (C_A), and cooling (C_R) were obtained by simulating the building with artificial conditioning. The relative consumption was equal to or less than the efficiency levels shown in Figures [8] and [9].

	EXTERNAL WALLS			Rsi= 0.13	Rse= 0.04
	Constitution	e (m)	λ (W/(mK))	R (m^2.K/(W))	U (W/(m^2K))
	Internal plaster	0.02	1.15	0.02	0.31
	Thermal Brick Weber	0.24	0.22	1.07	
	Thermal insulation - EPS	0.08	0.04	2.00	
	External plaster	0.02	1.15	0.02	

Legend: e = thickness, λ = thermal conductivity, R = thermal resistance, U = thermal transmittance

FIGURE 3- Composition of external walls according to NBR 15220:2005.

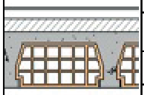
Source: Dalbem et. al. (2015, p.8).

	THERMAL BRIDGES			Rsi= 0.13	Rse= 0.04
	Constitution	e (m)	λ (W/(mK))	R (m^2K/(W))	U (W/(m^2K))
	Internal plaster	0.02	1.15	0.02	0.43
	Pillar/Concrete beam	0.24	1.75	0.14	
	Thermal insulation - EPS	0.08	0.04	2.00	
	External plaster	0.02	1.15	0.02	

Legend: e = thickness, λ = thermal conductivity, R = thermal resistance, U = thermal transmittance

FIGURE 4 - omposition of external walls - treatment of thermal bridges according to NBR 15220:2005.

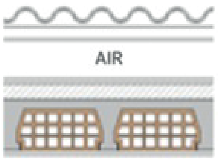
Source: Dalbem et. al. (2015, p.9).

	FLOOR			Rsi= 0.17	Rse= 0.17
	Constitution	e (m)	λ (W/(mK))	R (m^2/(WK))	U (W/(m^2K))
	Ceramic coating	0.01	0.90	0.01	0.40
	Mortar of settlement	0.04	1.15	0.02	
	Thermal insulation	0.08	0.04	2.00	
	Pre-molded slab	0.25	-	0.19	

Legend: e = thickness, λ = thermal conductivity, R = thermal resistance, U = thermal transmittance

FIGURE 5 -Composition of the floor slab, according to NBR 15220:2005.

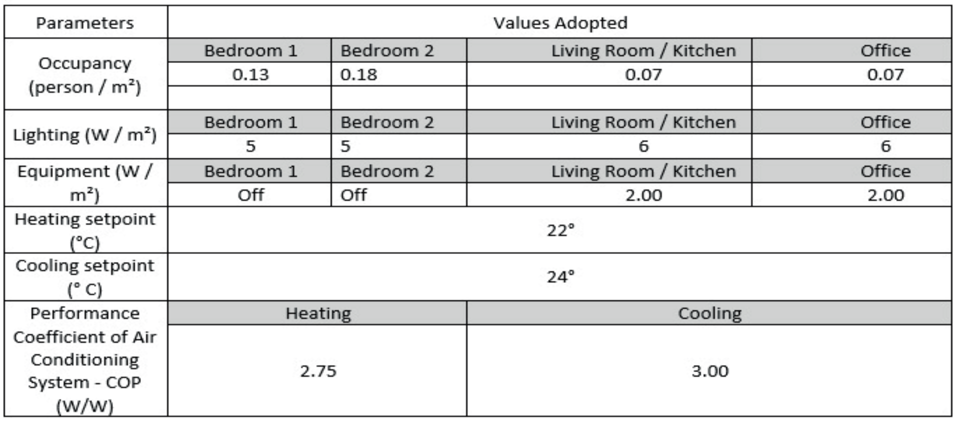
Source: Dalbem et. al. (2015, p.9).

	ROOF			Rsi= 0.10	Rse= 0.04
	Constitution	e (m)	λ (W/(mK))	R (m^2/(WK))	U (W/(m^2K))
	Internal plaster	0.02	1.15	0.02	0.41
	Pre-molded slab	0.25	-	0.19	
	Thermal insulation - EPS	0.08	0.04	2.00	
	External plaster	0.02	1.15	0.02	

Legend: e = thickness, λ = thermal conductivity, R = thermal resistance, U = thermal transmittance

FIGURE 6 - Roof Composition according to NBR 15220:2005.

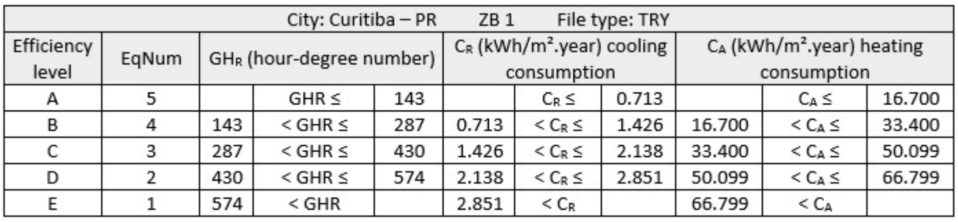
Source: Dalbem et. al. (2015, p.9).



Parameters	Values Adopted			
Occupancy (person / m²)	Bedroom 1	Bedroom 2	Living Room / Kitchen	Office
	0.13	0.18	0.07	0.07
Lighting (W / m²)	Bedroom 1	Bedroom 2	Living Room / Kitchen	Office
	5	5	6	6
Equipment (W / m²)	Bedroom 1	Bedroom 2	Living Room / Kitchen	Office
	Off	Off	2.00	2.00
Heating setpoint (°C)	22°			
Cooling setpoint (° C)	24°			
Performance Coefficient of Air Conditioning System - COP (W/W)	Heating		Cooling	
	2.75		3.00	

FIGURE 7 - Simulation parameters adopted.

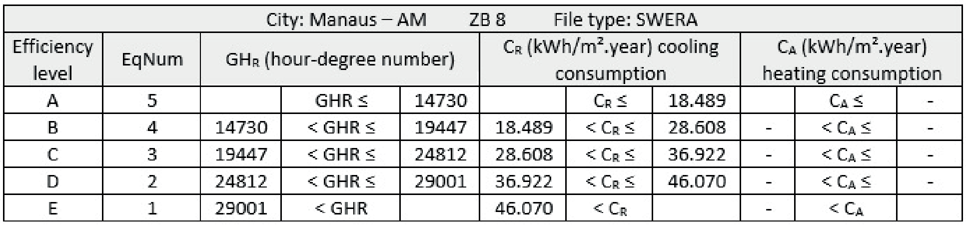
Source: adapted from RTQ-R (INMETRO, 2012).



City: Curitiba – PR ZB 1 File type: TRY										
Efficiency level	EqNum	GH_R (hour-degree number)			C_R (kWh/m².year) cooling consumption			C_A (kWh/m².year) heating consumption		
A	5		GHR ≤	143		$C_R \leq$	0.713		$C_A \leq$	16.700
B	4	143	< GHR ≤	287	0.713	$< C_R \leq$	1.426	16.700	$< C_A \leq$	33.400
C	3	287	< GHR ≤	430	1.426	$< C_R \leq$	2.138	33.400	$< C_A \leq$	50.099
D	2	430	< GHR ≤	574	2.138	$< C_R \leq$	2.851	50.099	$< C_A \leq$	66.799
E	1	574	< GHR		2.851	$< C_R$		66.799	$< C_A$	

FIGURE 8 - Cassification by the RTQ-R simulation method for ZB1.

Source: adapted from RTQ-R (INMETRO, 2012).



City: Manaus – AM ZB 8 File type: SWERA										
Efficiency level	EqNum	GH_R (hour-degree number)			C_R (kWh/m².year) cooling consumption			C_A (kWh/m².year) heating consumption		
A	5		GHR ≤	14730		$C_R \leq$	18.489		$C_A \leq$	-
B	4	14730	< GHR ≤	19447	18.489	$< C_R \leq$	28.608	-	$< C_A \leq$	-
C	3	19447	< GHR ≤	24812	28.608	$< C_R \leq$	36.922	-	$< C_A \leq$	-
D	2	24812	< GHR ≤	29001	36.922	$< C_R \leq$	46.070	-	$< C_A \leq$	-
E	1	29001	< GHR		46.070	$< C_R$		-	$< C_A$	

FIGURE 9 - Classification table by the simulation method for ZB8.

Source: adapted from RTQ-R (INMETRO, 2012).

Figures [8] and [9] show the efficiency levels for each weather file used and the degree-hour limit for each level. The degree-hour indicators obtained in the equation must be equal to or smaller than the indicated values. In order to determine the relative numeric equivalent for heating ($EqNumEnvAmb_A$) and cooling ($EqNumEnvAmb_A$) of each extended residence environment, it was necessary to determine the relative consumption for heating (C_A) and for cooling (C_R) of the prolonged use environments. Both values were obtained by simulating artificially conditioned buildings. The relative consumption was also equal to or less than the efficiency levels shown in Figures [8] and [9].

The numerical equivalent of the UH (independent housing unit) envelope for cooling ($EqNumEnv_{Resfr}$) and heating ($EqNumEnv_{A)}$ are obtained by weighting the useful areas of the evaluated environments (AU_{amb}). For climatic zone 1, the numerical equivalent of the envelope of the independent housing unit is obtained by the Equation 2.

$EqNumEnv=0,08xEqNumEnv_{Resfr}+0,92xEqNumEnv_{A}$ Equation 2

Source: Inmetro (2012)

Where:

EqNumEnv: Numerical equivalent of the UH envelope;

$EqNumEnv_{Resfr}$: Numerical equivalent of the UH envelope for cooling;

EqNumEnv: Numerical equivalent of the UH envelope for heating.

For climatic zone 8, the numerical equivalent of the envelope of the autonomous housing unit is obtained by Equation 3.

$EqNumEnv=EqNumEnv_{Resfr}$ Equation 3

Source: Inmetro (2012).

Where:

EqNumEnv: Numerical equivalente of the UH envelope;

$EqNumEnv_{Resfr}$: Numerical equivalente of the UH envelope for cooling.

The classification of the efficiency level of the building envelope varies from A (most efficient) to E (less efficient), and is determined from the final score obtained in the EqNumEnv. Equation.

Step 3 - Modelling the environment and analysing the shadow trace

Modelling the environment

In order to define the occupation of the surrounding land, the general guidelines of the Pelotas Master Plan (Law No. 1672) were adopted. According to the plan, in the region established for the construction of the building, called Residential Zone 1, 4 meters of landscaping retreat, 5m lateral recoil, 3.5m backtracking and 16m wide track are planned. The surrounding buildings were defined with eight different heights, starting from the no built environment, followed by environments of 2, 4, 6, 8, 10, 12 and 14. Each floor has a height of 3m, and the building has 21.84m in length and depth of 13.37m. In models over eight floors, decreasing 2m to each next model, because according to the Pelotas Master Plan, in buildings over 24m high the retreat of landscaping increases 1m for each floor that exceeds the characterised height.

Shadow Tracing

To better understand the influence of the shading of the surroundings in the building, a study of the shading was carried out for the of the Equinox, Summer and Winter Solstices. The impact of neighbouring buildings on the analysed building was observed in walls and roof, for the eight different environment scenarios. The study comprehended the following hours: 9:00h, 12:00h and 15:00h.

Stage 4 - Simulation of the energetic thermal performance of the residence

The simulation of the model configured according to the RTQ-R, previously presented in Figure [7], indicated the energy consumed by the building, adding the values of consumption of equipment and lighting and the consumption of air conditioning system (heating + cooling) obtained in kWh/m².year. The simulation makes possible to evaluate and compare the energy consumption of the building in the eight different surroundings possibilities, as well as to define the corresponding efficiency level. In this model the schedule was set to be naturally ventilated from 9:00h to 20:59h. and artificially conditioned from 21:00h. to 08:59h, with a heating thermostat temperature of 20°C.

The model, configured with 24-hours natural ventilation, followed by the configuration established by the RTQ-R for occupancy, internal equipment load and illumination power density. The value of 20°C, used by the RTQ-R as the setpoint air temperature for window openings in naturally ventilated buildings generated discomfort by cold, especially in the ZB1. Thus, a temperature of 25°C was defined as the setpoint for the window openings, as indicated by Martins (2009). The thermal comfort evaluation was based on the Adaptive Comfort model of the ASHRAE Standard 55 (ASHRAE, 2010). The monthly hourly averages were calculated in Microsoft Excel® software, based on the internal and external temperature output data obtained in the simulations. With the monthly average external temperature, it was possible, through equation 4, to calculate the operative comfort temperature month by month.

$Toc = 18{,}9 + 0{,}255\ Text$
Equation 4

Source: ASHRAE 55, 2010

Where:

Toc = Operative comfort temperature;

Text = External average monthly temperature.

In order to obtain the hours of thermal comfort inside environments, operative comfort temperatures of each month were used, calculated considering the comfort limit for 80% of acceptability, considering the values below the acceptability limit for cold discomfort and above of the limit for heat discomfort. With the building's thermal comfort hours, it was possible to compare the eight different heights of the surroundings, allowing us to evaluate the most suitable level of shading for the building with a high level of thermal envelope insulation in Brazilian climatic zones 1 and 8.

Step 5 – Analysis and Discussion of Results

A comparison of the thermal-energetic performance of the highly insulated building was made for the three base configurations, with different ventilation conditions for the eight scenarios of shadowing. The efficiency level of the envelope for the summer was obtained from the model configured for ventilation conditions according to the parameters of RTQ-R. The energy consumption for heating (kWh/m2.year) defined the energy efficiency level for the winter. Both results for summer and winter defined the envelope's energy efficiency level. The energy consumption of the residence (kWh/

m2.year) through the 24 hours artificially air-conditioned model and the level of adaptive thermal comfort with 24 hours naturally ventilated were used as the comparative analysis parameters.

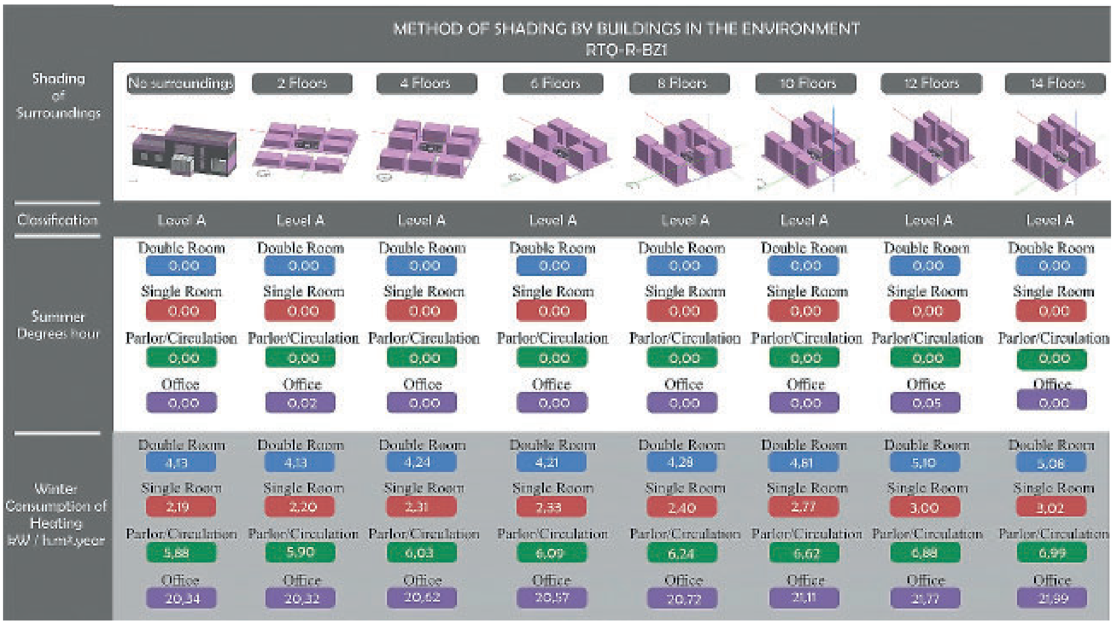
Analysis of Results

Building with ventilation settings according to RTQ-R

In order to define the envelope efficiency level of a high insulated residence, the model was configured with the parameters of RTQ-R. For climatic zone 1, it obtained classification A, and for climatic zone 8, level B, as shown in [10] and [11]. Long-stay rooms were evaluated and simulations indicated energy consumption and degree-hour indicator for cooling, having 26°C as base temperature.

In climatic zone 1 the degree-hour climatic zone with lower temperatures, something that contributes to not so high internal temperatures. In zone 8, with higher temperatures, it can be observed that the degree-hour indicator for cooling showed higher values, indicating that in all cases at some point temperature in the internal environment exceeded 26°C.

Regarding the heating consumption, in climatic zone 1, we can observe that the model with no buildings in the surroundings is the one that presented the lowest consumption. The model surrounded by the 14 floors buildings showed the highest consumption. For that colder climate, the excessive shadowing is not favourable, because with lower temperatures the lack of thermal gain by solar radiation becomes a problem, and the use of artificial climatisation for internal spaces heating ends up being necessary, increasing energy consumption. We can observe in Figures [18], [19], [20] and [21] the shadow tracking in the winter and summer solstice respectively. The 14-storey environment model shows total shading of both the vertical and horizontal closures, thus decreasing the heat gains by direct solar radiation.

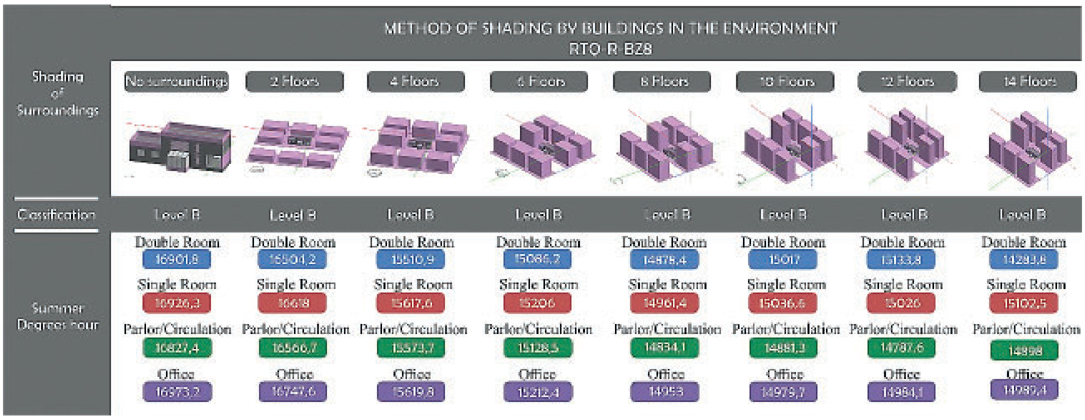


METHOD OF SHADING BY BUILDINGS IN THE ENVIRONMENT
RTQ-R-BZ1

Shading of Surroundings		No surroundings	2 Floors	4 Floors	6 Floors	8 Floors	10 Floors	12 Floors	14 Floors
Classification		Level A	Level A	Level A	Level A	Level A	Level A	Level A	Level A
Summer Degrees hour	Double Room	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Single Room	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Parlor/Circulation	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Office	0,00	0,02	0,00	0,00	0,00	0,00	0,05	0,00
Winter Consumption of Heating kW / hum².year	Double Room	4,13	4,13	4,24	4,21	4,28	4,61	5,10	5,06
	Single Room	2,19	2,20	2,31	2,33	2,40	2,77	3,00	3,02
	Parlor/Circulation	5,88	5,90	6,03	6,09	6,24	6,62	6,88	6,99
	Office	20,34	20,32	20,62	20,57	20,72	21,11	21,77	21,99

FIGURE 10 - Classification of the efficiency level of the building considering the RTQ-R in Brazilian climatic zone 1, 2017.

Source: Authors, 2017



METHOD OF SHADING BY BUILDINGS IN THE ENVIRONMENT
RTQ-R BZ8

Shading of Surroundings	No surroundings	2 Floors	4 Floors	6 Floors	8 Floors	10 Floors	12 Floors	14 Floors
Classification	Level B	Level B	Level B	Level B	Level B	Level B	Level B	Level B
Summer Degrees hour	Double Room 16901,8	Double Room 16504,2	Double Room 15510,9	Double Room 15086,7	Double Room 14878,4	Double Room 15017	Double Room 15133,8	Double Room 14283,8
	Single Room 16926,3	Single Room 16618	Single Room 15617,6	Single Room 15206	Single Room 14961,4	Single Room 15036,6	Single Room 15026	Single Room 15102,5
	Parlor/Circulation 16827,4	Parlor/Circulation 16566,7	Parlor/Circulation 15573,7	Parlor/Circulation 15128,5	Parlor/Circulation 14834,1	Parlor/Circulation 14881,3	Parlor/Circulation 14787,6	Parlor/Circulation 14898
	Office 16973,2	Office 16747,6	Office 15619,8	Office 15212,4	Office 14953	Office 14979,7	Office 14984,1	Office 14980,4

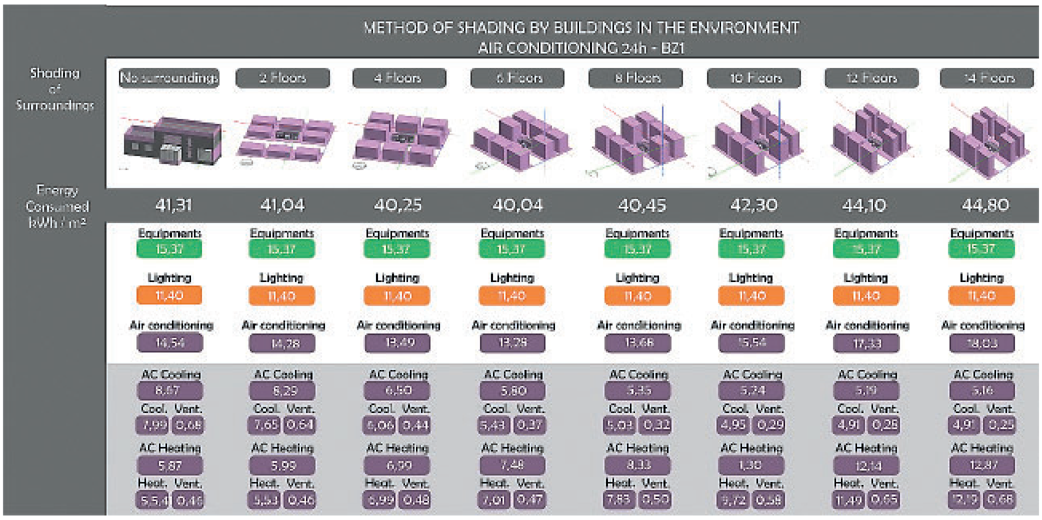
FIGURE 11 -Classification of the efficiency level of the building considering the RTQ-R in Brazilian climatic zone 8, 2017.

Source: Authors, 2017

24-hour artificially conditioned building

Figures [12] and [13] present the values of building's energy consumption for the eight shading scenarios. As we can see, in climatic zone 1 the model with the 14 floors surroundings presented the highest energy consumption, of 44.80 kWh / m².year; and the environment with 6 floors the lowest, 40.04 kWh/m².year, with a difference of 10.63% between them. From these results we observe that for this zone the excessive shading is detrimental to the good functioning of the high insulated building.

As for the model with the 14 floors surroundings, presents almost full shade coverage at all times of the winter and summer solstices, except for noon on the summer solstice, since it does not allow thermal gains by direct solar radiation, thus increasing the energy expenditure for heating. In zone 8, the environment with 14 floors, which generates greater shading on the building, was more efficient. It presented an energy consumption of 97.84 kWh / m².year, 6.70% smaller than the no buildings surroundings, which presented a consumption of 104.87 kWh / m².year. That consumption was exclusively for cooling since climatic zone 8 has high air temperatures and humidity. For that climate, the total shading of the building (walls and roof), would decrease the discomfort by warmth indoors. The lack of direct solar radiation, thus, contributes but is not enough to eliminate that discomfort by warmth, indoors, in naturally ventilated buildings (including the insulated one).



METHOD OF SHADING BY BUILDINGS IN THE ENVIRONMENT
AIR CONDITIONING 24h - BZ1

Shading of Surroundings	No surroundings	2 Floors	4 Floors	6 Floors	8 Floors	10 Floors	12 Floors	14 Floors
Energy Consumed kWh / m²	41,31	41,04	40,25	40,04	40,45	42,30	44,10	44,80
Equipments	15,37	15,37	15,37	15,37	15,37	15,37	15,37	15,37
Lighting	11,40	11,40	11,40	11,40	11,40	11,40	11,40	11,40
Air conditioning	14,54	14,28	13,49	13,28	13,68	15,54	17,33	18,03
AC Cooling	8,67	8,29	6,50	5,80	5,35	5,24	5,19	5,16
Cool.	7,99	7,65	6,06	5,43	5,03	4,95	4,91	4,91
Vent.	0,68	0,64	0,44	0,37	0,32	0,29	0,28	0,25
AC Heating	5,87	5,99	6,99	7,48	8,33	1,30	12,14	12,87
Heat.	5,54	5,53	6,99	7,01	7,83	9,72	11,49	12,19
Vent.	0,46	0,46	0,48	0,47	0,50	0,58	0,65	0,68

FIGURE 12 - Classification of the level of energy consumption with the use of 24-hour air conditioning in climatic zone 1, 2017.

Source: Authors, 2017

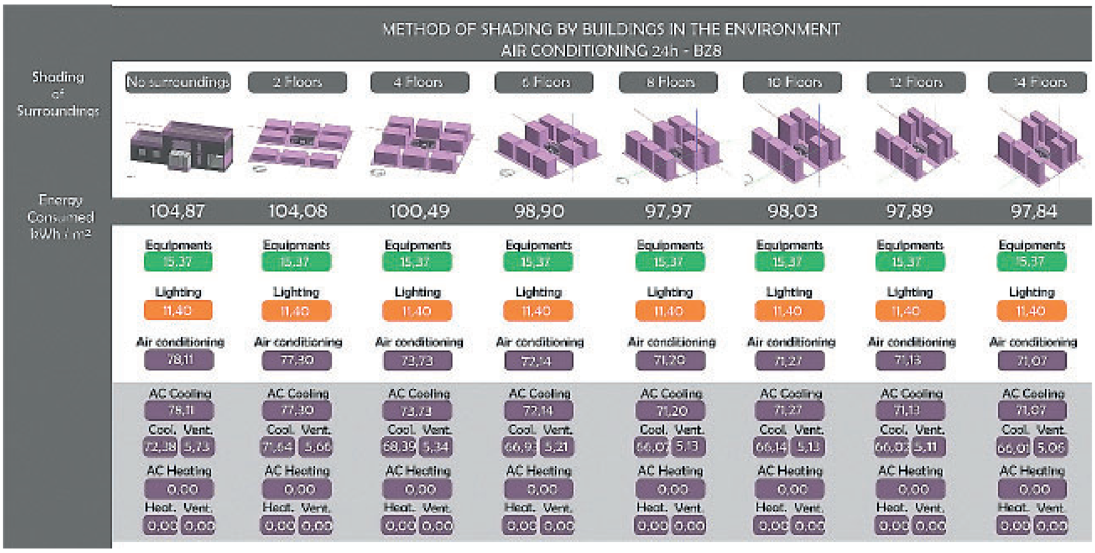


FIGURE 13 - Classification of the level of energy consumption with the use of 24-hour air conditioning in climatic zone 8, 2017.

Source: Authors, 2017

24 hours naturally ventilated building

In Figures [14] and [15], energy consumption values of the building are presented for the eight shading scenarios. As we can see, in climatic zone 1 the model with the 14 floors surroundings presented the highest energy consumption, of 44.80 kWh / m².year; and the environment with 6 floors the lowest, 40.04 kWh/m².year, with a difference of 10.63% between them. From these results we observe that for this zone the excessive shading is detrimental to the good functioning of the high insulated building. As for the model with the 14 floors surroundings, as shown in Figures [18], [19], [20] e [21], presents almost full shade coverage at all times of the winter and summer solstices, with the exception of noon on the summer solstice, since it does not allow thermal gains by direct solar radiation, thus increasing the energy expenditure for heating. In zone 8, the environment with 14 floors, which generates greater shading on the building, was more efficient because it presented an energy consumption of 97.84 kWh / m².year, 6.70% smaller than the no buildings surroundings, which presented consumption of 104.87 kWh / m².year, this consumption being exclusively for cooling, due to the fact that climatic zone 8 has high temperatures, with which, even with the total shading of the building, walls and cover, performance is not hampered by the lack of direct radiation and its interior remains warm.

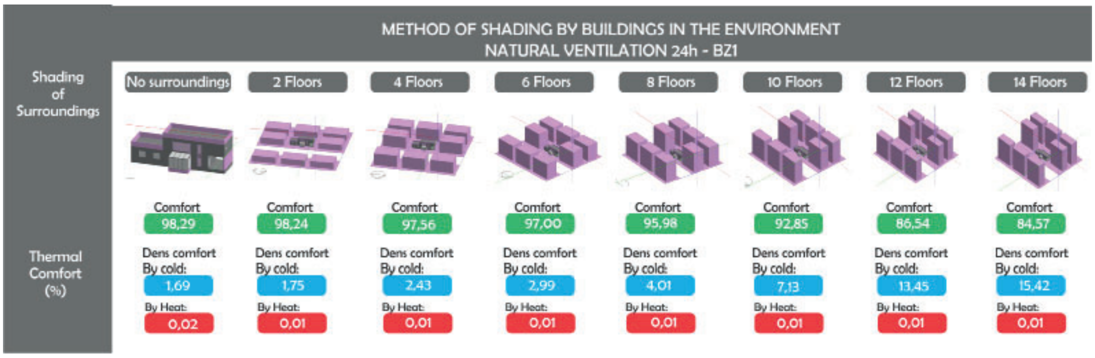
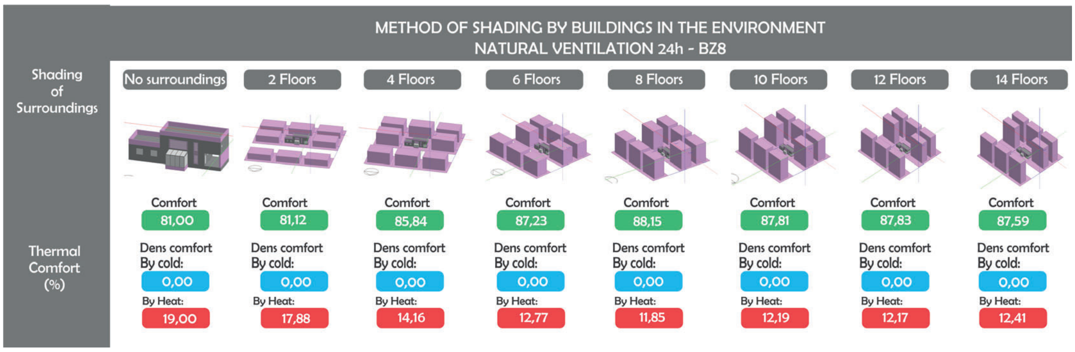


FIGURE 14 - Thermal comfort infographic in climatic zone 1, 2017.

Source: Authors, 2017



METHOD OF SHADING BY BUILDINGS IN THE ENVIRONMENT
NATURAL VENTILATION 24h - BZ8

Shading of Surroundings	No surroundings	2 Floors	4 Floors	6 Floors	8 Floors	10 Floors	12 Floors	14 Floors
Thermal Comfort (%)	Comfort 81,00	Comfort 81,12	Comfort 85,84	Comfort 87,23	Comfort 88,15	Comfort 87,81	Comfort 87,83	Comfort 87,59
	Dens comfort By cold: 0,00	Dens comfort By cold: 0,00	Dens comfort By cold: 0,00	Dens comfort By cold: 0,00	Dens comfort By cold: 0,00	Dens comfort By cold: 0,00	Dens comfort By cold: 0,00	Dens comfort By cold: 0,00
	By Heat: 19,00	By Heat: 17,88	By Heat: 14,16	By Heat: 12,77	By Heat: 11,85	By Heat: 12,19	By Heat: 12,17	By Heat: 12,41

FIGURE 15 - Thermal comfort infographic in climatic zone 8, 2017.

Source: Authors, 2017

In the 24 hours a day naturally ventilated building, we can see in [14] that for climatic zone 1 the model with no environment was more efficient, with 98.29% of thermal comfort, and the one with 14 floors buildings the less efficient, with 84,57%. It presents only 0.01% of heat discomfort, because it is an area with milder temperatures and the excessive shading of the roof compromises the building's performance, since it reduces heat gains by direct radiation. In climatic zone 8, which presents higher temperatures, shading becomes desirable, since it improves the building's performance, as shown in [15]. The model without environment presented the lowest thermal comfort index, with 81%, and the model with the 8 floors environment the largest, with 88.15%, not presenting cold discomfort. As we can see in Figures [18], [19], [20] and [21] of the shade tracking, the model with an environment of 8 pavements is the configuration that shows greater shading at 9:00h and 15:00h, both in the autumn and spring equinoxes, and in the winter and summer solstices.

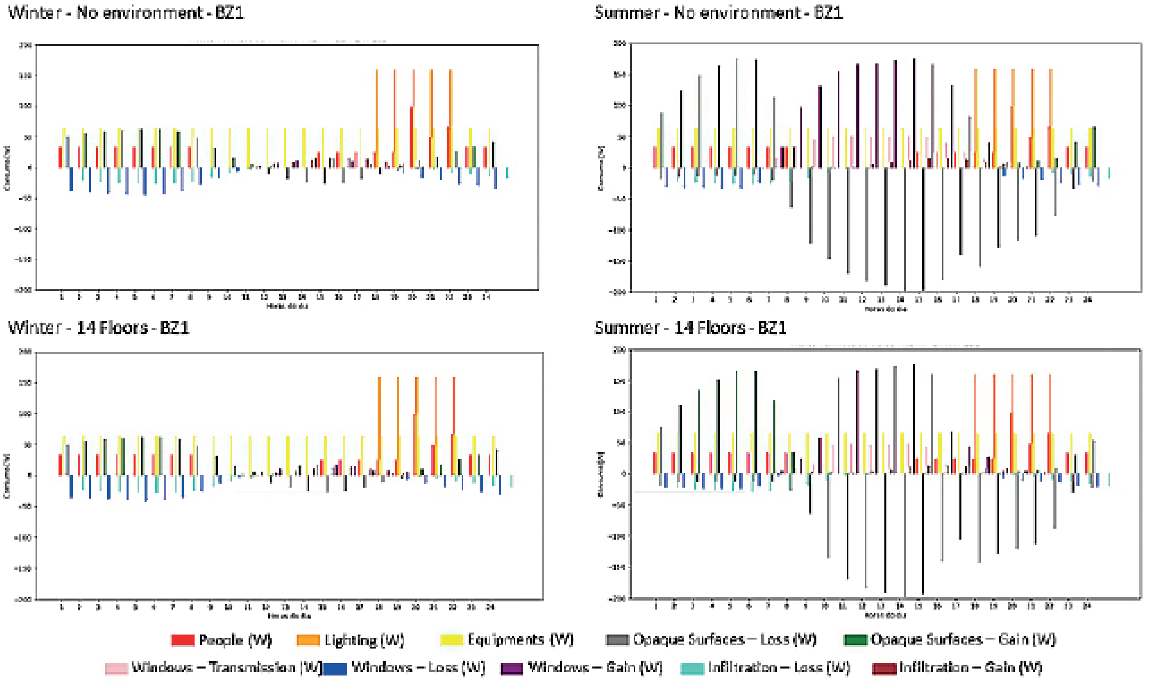
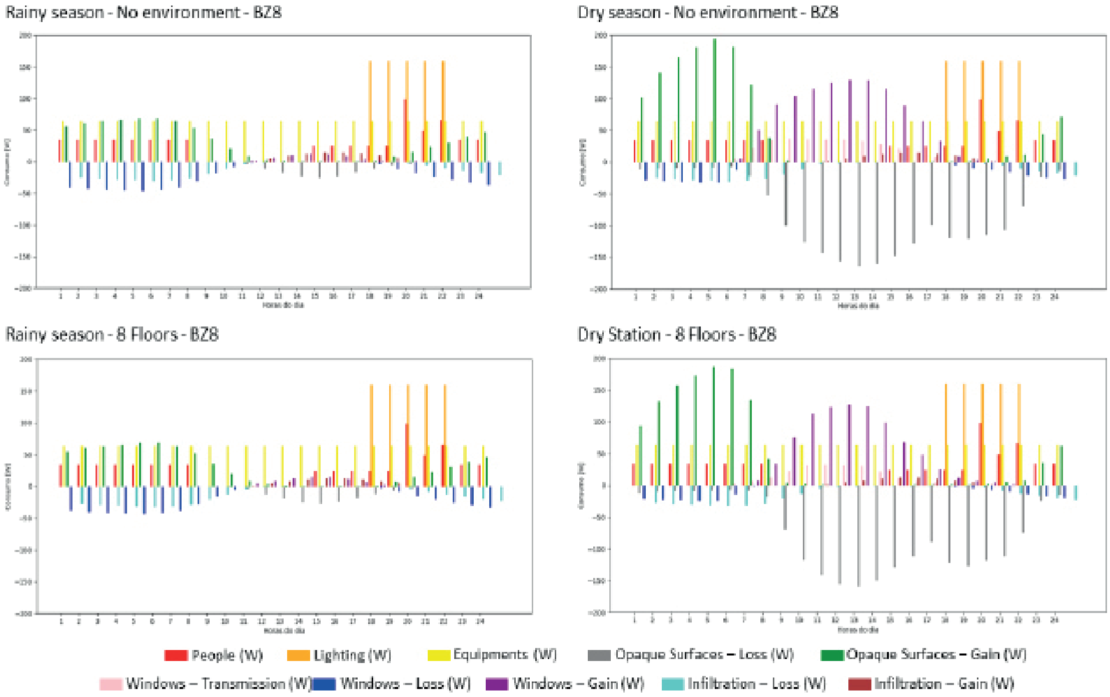


FIGURE 16 - Thermal Flow for the 24 hours naturally ventilated building - Brazilian Climatic Zone 1, 2017.

Source: Authors, 2017



Rainy season - No environment - BZ8

Dry season - No environment - BZ8

Rainy season - 8 Floors - BZ8

Dry Station - 8 Floors - BZ8

FIGURE 17 - Thermal Flow for the 24 hours naturally ventilated building - Brazilian Climatic Zone 8, 2017.

Source: Authors, 2017

The thermal fluxes, presented in Figures [16] and [17], explain more clearly the results obtained in the simulations of the 24 hours naturally ventilated model. In climatic zone 1, the model with no environment, more efficient, presented a thermal comfort percentage 13.96% higher than the environment with 14 floors, less efficient. It can be noticed that winter heat gains are very close in both models, but in summer, the window heat gains occur for a longer period in the model without surroundings. Since it is a zone with cooler climates, in order to avoid a great level of cold discomfort, the heat gains are favorable for good performance of the building. As for climatic zone 8, where the climate has higher temperatures, shading becomes favorable to the good performance of the building. In this area, the model with an 8-floor environment presented a thermal comfort percentage 8.11% greater than the model without surroundings. As in climatic zone 1, for the winter the heat gains are very close, but in the summer, the heat gains by windows and opaque surfaces in the model without surroundings are greater than those of the model with 8 floors.

Shadow tracing

From the study of shadow tracking, it was possible to observe the shadows generated by each environment in the residence, allowing a better understanding of the results, as shown in [18] and [19] for climatic zone 1, and [20] and [21], for climatic zone 8.

In climatic zone 1, we observe that in autumn and spring at 9:00 am the construction with an environment of 2, 4, 6, 8, 10 and 12 floors is shaded on the façades and a small part of the roof, with direct solar radiation in the cover. In the model with not surroundings and with 14 floors, the building presents only its own shading in the facades west and south. At noon the building has its own shade on the South façade, not receiving shading from the surrounding buildings. At 15:00h, in the models with no surroundings, with 2, 4, 12 and 14 floors, the building has only its own shading in part of the roof and in the East and South façades; and in models with 6, 8 and 10 floors it also receives the shading of surrounding buildings on the West façade and part of the roof. In winter, at 9:00 p.m., in the model with no surroundings and in the environment of 2 floors, the residence does not have influence from the environment regarding shading. At 12:00 noon, in the model with no surroundings and in the one with surroundings of 2, 4 and 6 floors, the building had its own shading in the South façade. In the model with 8 floors, there was the building's own shading in the South façade and shading of the surroundings in the North one, while in models with 10, 12 and 14 floors, the residence showed its own and the surroundings shading in its façades and in the roof. At 15:00h, the building had almost total shading in the models with surroundings of 10, 12 and 14 floors, partial with surroundings of 6 and 8 floors and only its own shade in South and East façades in the models with no surroundings, 2 and 4 floors. Regarding the summer, the building presented, at 9:00h, total shading of the roof with 10, 12 and 14 floors, partial with 4, 6 and 8 and only its own shading, in North and West façades, in the model with no surroundings and with 2 floors. At noon, the building is totally exposed to direct radiation in all models, because it receives no shadow of the surroundings or even the building itself. At 15:00h, the building received almost total shading in the roof with the surroundings of 12 and 14 floors, partial in the models with 4, 8, 6 and 10 floors and only its own shading, in the East façade, with no surroundings and with 2 floors.

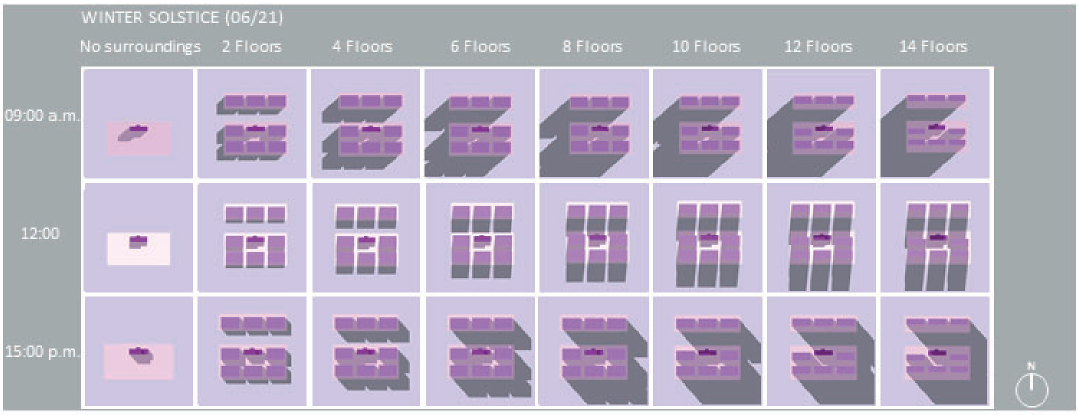


FIGURE 18- Solar tracking in the winter solstice - Climatic zone 1, 2017.

Source: Authors, 2017

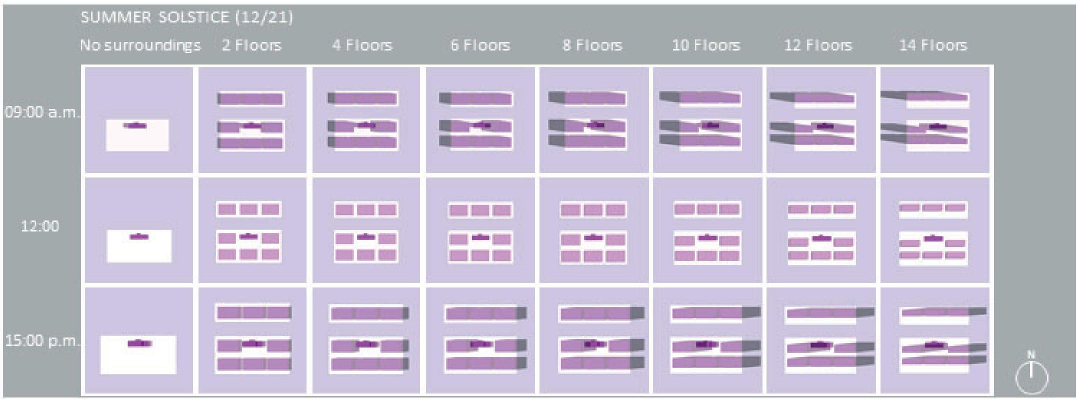


FIGURE 19 - Solar tracking in the summer solstice - Climatic zone 1, 2017.

Source: Authors, 2017

For climatic zone 8, the results were slightly different from those obtained in climatic zone 1. In autumn and spring, at 9:00h, in the models with no surroundings and the ones with two floors, the building received direct radiation throughout its coverage, presenting shading only in the West façade. As for the models with 4, 6, 8, 10 and 12 floors, the building was partially shaded on the roof, and the surroundings shaded the model with 14 floors on the South façade and in a small part of the roof.

At 12:00h, the building receives direct solar radiation in its entire envelope, because it does not present shading from itself or surroundings. At 15:00h, the study of shadow tracking was similar to that of 9:00h, except that the building itself shaded the East façade. In winter, it was observed that at 9:00h, in the models with no surroundings and with surroundings of 2, 12 and 14 floors, the building has only its shading, in the South and West façades. In models with 4, 6, 8 and 10 floors, the building had its façades and roof partly shaded by the surroundings.

The same behaviour could be observed at 15:00h, however, in this case, in the 4-storey model the building had only the facades shaded, leaving the cover exposed. At noon the building has its own shade on the South façade, leaving the roof wholly exposed to direct solar radiation. In summer, shade tracking at 9:00h presents, in models with no surroundings and the ones with 2 floors, the building's own shading in the North and West façades, partial shading of the cover in the models with surroundings of 4, 6, 8, 10 and 12, and total shading of the cover in the 14-floor model.

At 12:00h in the models without surroundings and with 2, 4, 6, 8 and 10 floors, the building has its shading in the north façade and the 12 and 14 floors. Besides the building's shading, the surroundings generated shade on the South façade, thus getting the roof fully exposed to direct solar radiation. At 15:00h, results resembled those from 9:00h, although the 4-floors environment generates shade only on the West façade of the building, and not on the roof.

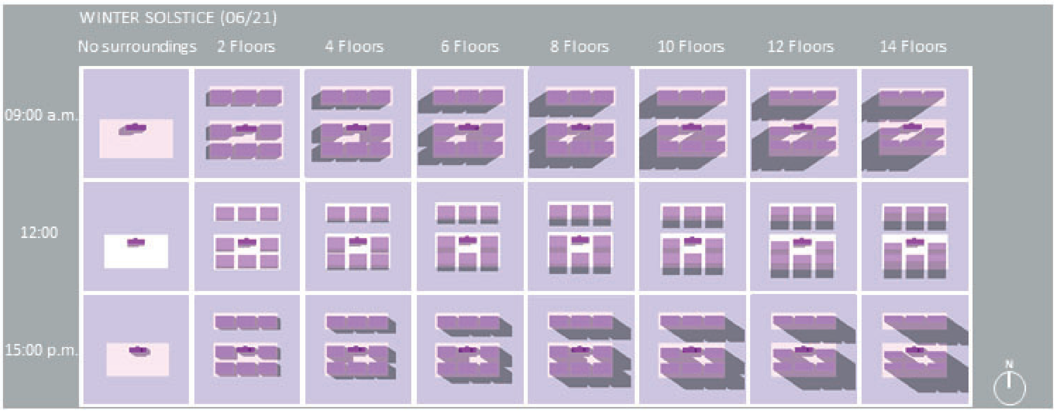


FIGURE 20- Solar tracking in the winter solstice - Climatic zone 1, 2017.

Source: Authors, 2017.

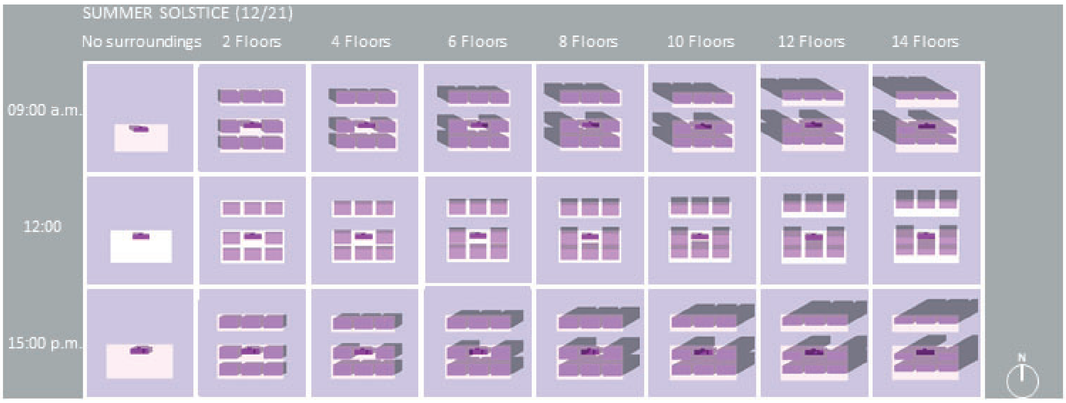
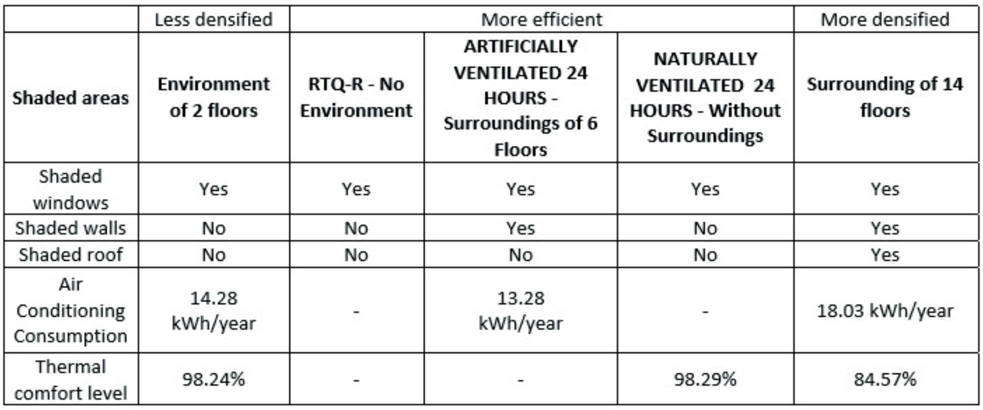


FIGURE 21 - Solar tracking in the winter solstice - Climatic zone 1, 2017.

Source: Authors, 2017.

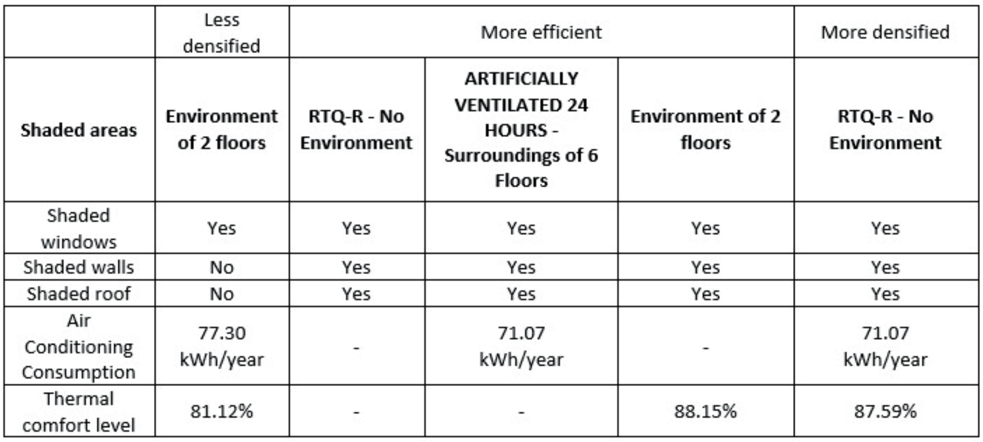
A summary of results is shown in Figure [22] for climatic zone 1 and in Figure [23] for climatic zone 8. We observed that in climatic zone 1, the model with 6-floor environment presented the lowest consumption and the higher thermal comfort index. That result is explained because, as previously mentioned, in this case, the temperatures are milder, so excessive shadowing may impair the performance of the building. In climatic zone 8, the model with 14 floors environment presented the lowest consumption and the 8 floors environment the highest thermal comfort index. That is explained by temperatures in this zone being higher, so a higher amount of shading may favour the performance of a super-insulated building.



	Less densified	More efficient			More densified
Shaded areas	**Environment of 2 floors**	**RTQ-R - No Environment**	**ARTIFICIALLY VENTILATED 24 HOURS - Surroundings of 6 Floors**	**NATURALLY VENTILATED 24 HOURS - Without Surroundings**	**Surrounding of 14 floors**
Shaded windows	Yes	Yes	Yes	Yes	Yes
Shaded walls	No	No	Yes	No	Yes
Shaded roof	No	No	No	No	Yes
Air Conditioning Consumption	14.28 kWh/year	-	13.28 kWh/year	-	18.03 kWh/year
Thermal comfort level	98.24%	-	-	98.29%	84.57%

IGURE 22 - Summary of shading of residential building - Climatic Zone 1, 2017.

Source: Authors, 2017.



	Less densified	More efficient			More densified
Shaded areas	**Environment of 2 floors**	**RTQ-R - No Environment**	**ARTIFICIALLY VENTILATED 24 HOURS - Surroundings of 6 Floors**	**Environment of 2 floors**	**RTQ-R - No Environment**
Shaded windows	Yes	Yes	Yes	Yes	Yes
Shaded walls	No	Yes	Yes	Yes	Yes
Shaded roof	No	Yes	Yes	Yes	Yes
Air Conditioning Consumption	77.30 kWh/year	-	71.07 kWh/year	-	71.07 kWh/year
Thermal comfort level	81.12%	-	-	88.15%	87.59%

FIGURE 23 - Summary of shading of residential building - Climatic Zone 8, 2017.

Source: Authors, 2017.

Conclusions

The ideal levels of shadowing, thus, varied. For the warmer climate (ZBB8), the best performance was obtained with the higher level of shadowing (applied to the external walls and roof), confirming the climate-responsive design strategy fairly indicated to that ZBB. Conversely, for the colder climate (ZBB1), the best performance was achieved with a lower level of shadowing, including only the external walls. Results confirmed the relationship between the amount of shading indicated to improve the thermal-energetic performance of a building and the climate where it is built. A shaded building with a high level of thermal insulation adapts more easily to warmer climates. The high thermal insulation of the opaque envelope elements reduces the heat flow. In warmer climates, the high temperature of the environment added to the direct solar gain, overheats the interior of the building, making it necessary to use artificial conditioning to seek the user's thermal comfort.

Conversely, in colder climates (Brazilian climatic zone 1), the model with the best thermal-energetic performance was the one with no surroundings, for the ventilation conditions according to the RTQ-R and 24 hours naturally ventilated; and with surroundings of 6 floors, for the 24 hours artificially ventilated model. The sunlight protection system blocks direct solar radiation inside the building during the summer period. In the winter period, total shading of the vertical and horizontal plane decreases the envelope thermal-energetic performance, thus impacting the generated heat quantity by direct solar radiation inside the building. In this zone, direct solar radiation is necessary, not only in the horizontal plane but also in the vertical one, because the thermal gains provided by the internal gains coming from the lighting system, the occupation and the equipment, are not sufficient to maintain the temperature in comfort conditions. In the models with greater densification of the surroundings, the building presents a greater discomfort by cold, indoors. As for climatic zone 8, the model in which the building presented the best thermal-energetic performance was the one with the 14 floors environment, for the ventilation conditions according to the RTQ-R and 24 hours artificially ventilated, 8 floors, for the 24-hours naturally ventilated one.

We observed that even with the solar protection system blocking the direct solar radiation inside the building in the summer, the total or partial shading of the vertical and horizontal planes is necessary to guarantee the good thermal-energetic performance of the envelope. The thermal gains from the lighting system, the occupancy and the equipment, are enough to overheat the interior of the building. Therefore, in this warmer climatic zone, the configurations that present greater densification of the environment are more efficient than the less densified ones. The issues addressed in this article, which discuss the shading of the vertical and horizontal planes of buildings with a high level of thermal insulation, fill a gap in the context of thermal energy performance of residential buildings, exemplifying its relation with the urban configuration of specific regions in Brazil.

Although the occupants might influence results, that contribution was analysed through a standardised profile, defined by RTQ-R. A parametrical study on the influence of user's behaviour on results would represent interesting follow-up research.

Referências

ABNT – BRAZILIAN NATIONAL STANDARDS ORGANIZATION. **Standard NBR 15.220: Brazilian Standard for Thermal Performance of Buildings.** Rio de Janeiro, 2005.

ABNT – BRAZILIAN NATIONAL STANDARDS ORGANIZATION. **Standard NBR 15.575: Residential Buildings – Performance**. Rio de Janeiro, 2013.

ANSI/ASHRAE – AMERICAN NATIONAL STANDARD INSTITUTE / AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS. **Standard 55: Thermal Environmental Conditions for Human Occupancy**. Atlanta, 2010.

DALBEM, Renata; FREITAS, J.R; AUTOR. **Conceito Passivhaus Aplicado ao Clima Brasileiro. [Passivhaus Concept applied to Brazilian Climate].** Revista de Arquitetura IMED [IMED Architecture Magazine], Passo Fundo, v. 4, p. 26-36, 2015.

DALBEM, Renata, et al. **Discussão do desempenho da envoltória de uma passive house adaptada à zona bioclimática 2 em acordo com o RTQ-R. [Discussion on the performance of a passive house envelope when adapted to climatic zone 2 according to RTQ-R].** Ambiente Construído [Built Environment], v.17, no.1, p.201-222, Mar 2017.

DUARTE, Luciane Cleonice; NOGUEIRA, Marta Cristina de J. A. **Sombreamento arbóreo e desempenho termoenergético de edificações. [Tree Shading and thermoenergetic performance in buildings]** In: Encontro Nacional de Tecnologia do Ambiente Construído [National Meeting of Technology of Built Environments]. Annals. Juiz de Fora, ENTAC, 2012.

EPBD (2010). **Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.** Official Journal, European Union Legislation, v. 53, n.153, p. 13-35, 2010.

INMETRO – NATIONAL INSTITUTE OF METROLOGY STANDARDIZATION AND INDUSTRIAL QUALITY. **RTQ-C. Technical Requirements for Quality of Energy Efficiency Levels in Commercial, Services and Public Buildings.** INMETRO, Rio de Janeiro, 2013.

INMETRO - INSTITUTO NACIONAL DE METROLOGIA, NORMALIZAÇÃO E QUALIDADE INDUSTRIAL. **RTQ-R. Technical Requirements for Quality of Energy Efficiency Levels in Residential Buildings. I**NMETRO, Rio de Janeiro, 2012.

LITTLEFAIR, Paul; ORTIZ, Jose; BHAUMIK, Claire Das. **A simulation of solar shading control on UK office energy use. Building Research & Information,** v. 38, n. 6, p. 638-646, 2010.

MARTINS, D. J.; RAU, S. L.; RECKZIEGEL, S.; FERRUGEM, A. P.; SILVA, A. C. S. B. **Ensaio sobre a Utilização da Automação de Aberturas na Simulação do Desempenho Térmico de Edificações. [Essay on the Use of Automation of Openings for Simulating Thermal Performance of Buildings]** In: Encontro Nacional de Conforto no ambiente Construído [National Meeting of Comfort of the Built Environment], 10. Annals Natal, ENTAC, 2009.

MASCARÓ, Lúcia; MASCARÓ, Juan José. **Ambiência Urbana [Urban Ambience].** Porto Alegre: Masquatro, 2009.

OLBINA, Svetlana; BELIVEAU, Yvan. **Developing a transparent shading device as a daylighting system.** Building Research & Information, v. 37, n. 2, p. 148-163, 2009.

PACHECO, Miguel. **Ventilação Natural e Climatização Artificial: Crítica ao modelo Super-isolado para residência de energia zero em Belém e Curitiba [Natural Ventilation and Artificial Climatization: Critique of the Super-Isolation Model for Zero-**

-Energy Houses in Belém and Curitiba]. Thesis (Doctorate in Civil Engineering). Federal University of Santa Catarina, Florianópolis, 2013.

PASSIVE-ON PROJECT. **A norma Passivhaus directrizes de projecto para casas confortáveis de baixo consumo energético, Parte I. Revisão de casas confortáveis de baixo consumo energético [The Passivhaus project guidelines for comfortable low energy consumption houses** Part 1. Review on comfortable low energy consumption houses]. Lisboa: INETI, 2007.

PEREIRA, Silvia Ruzicki ; DUARTE, Carolina de Mesquita ; CUNHA, Eduardo G. da ; KREBS, Lisandra Fachinello ; EITZKE, R. K. ; SILVA, Antônio César Baptista da ; BENINCA, L. **EFEITOS DO SOMBREAMENTO NO DESEMPENHO TERMOENERGÉTICO DE EDIFICAÇÃO ISOLADA NO SUL DO BRASIL [EFFECTS OF SHADING IN THERMOENERGETIC PERFORMANCE OF AN ISOLATED BUILDING IN SOUTHERN BRAZIL].** PARC: Pesquisa em Arquitetura e Construção [Research on Architecture and Construction], v. 7, p. 145-159, 2016.

POUEY, Juliana Al-Alam. **Projeto de edificação residencial unifamiliar para a zona bioclimática 2 com avaliação termo energética por simulação computacional. [Project of residential single family building for climatic zone 2 with thermoenergetic assessment through computer simulation].** Master Thesis (Master in Architecture), Post-Graduation Program in Architecture, Federal University of Pelotas, Pelotas, 2011.

PELOTAS CITY HALL, Law 1672, Pelotas Master Plan. 2008.

ROMERO, Marta. **Correlação entre o microclima urbano e a configuração do espaço residencial de Brasília [Correlation between urban microclimate and the configuration of residential space in Brasília].** Fórum Patrimônio. v. 4, n.1, 2011.

SALAZAR, Jorge Hernán. **Sunlighting evaluation in buildings: Shading device evaluation method with qualitative comparisons between various shading alternatives allows quick and accurate choice of most suitable solution with cost benefits.** Building research and information, v. 23, n. 3, p. 182-187, 1995.

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