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Sensibility Analysis of the Brazilian Standards for Energy Efficiency Regarding the Variation of Internal Load Density in Office Buildings in Brazilian Bioclimatic Zones 1 and 7

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Abstract: The RTQ-C (*Technical Requirements of Quality for the Energy Performance Level of Commercial Buildings*) publication classified the buildings in five efficiency levels. In RTQ-C, the evaluation can be done with two methods: a prescriptive method and a simulation one. This paper aims to identify the sensibility of the prescriptive method RTQ-C regarding the variation of equipment internal load density in office buildings in bioclimatic Zones 1 and 7 of the Brazilian bioclimatic zoning. The research results show that the building with walls and roof configured to meet specific prerequisites for energy efficiency Levels B and C had a lower consumption than buildings that meet the prerequisites to Level A. The study also showed that buildings with high internal load density of equipment, maximum shape factor and high, with walls and roofs with higher thermal transmittance, have lower power consumption than constructions with an envelope with greater thermal resistance. The increase in internal load density causes an increase in the internal heat generated by the large amount of equipment. In buildings with higher thermal insulation (Level A), the internal heat is maintained in the environment, causing overheating and the need for an air conditioning system.

Key words: RTQ-C, internal load density, office buildings, energy modeling, energy efficiency in buildings.

1. Introduction

In Brazil, the first governmental programs and specific legislations that aimed at energy efficiency appeared in the 1980s, with the creation of PBE (Brazilian Labeling Program) and PROCEL (National Program for Electric Energy Conservation). The PBE has the objective of informing consumers about the performance of products, regarding conditions such as energy efficiency and noise, for example. The PROCEL has the objective of promoting rationalization of electricity consumption to combat waste and reduce costs and sector investments, increasing energy efficiency.

In 2001, Brazil faced a crisis in the energy sector and public attention turned to this problem. At that time, the government had to look for more effective measures related to the rationalization of electricity consumption. The first step was the publication of *Law 10295*, on October 17, 2001 [1], which determined that the energy-using equipment produced domestically or imported, as well as the buildings constructed in the country, should meet the minimum energy efficiency requirements. In December of that same year, Decree No. 4059, regulating *Law No. 10295*, was published, and the creation of the working group on buildings was also established, which presented a way to regulate the buildings constructed in Brazil to encourage rational use of electricity in the country [2].

After some years of discussion and work, the INMETRO (National Institute for Metrology, Quality and Technology) published the first version of the RTQ-C (*Technical Quality Requirements for Energy Efficiency Level in Commercial, Public and Service*

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Buildings) in 2007, having its final version published in 2009. Soon after, in 2010, the RTQ-R (*Quality Technical Standards for Energy Efficiency Level in Residential Buildings*) was published, too.

The RTQ-C aims to develop conditions for the labeling of the energy efficiency level of commercial, services and public buildings, discriminating the technical requirements to be assessed and methods for classification of buildings regarding energy efficiency, to obtain the ENCE (National Energy Conservation Label). To classify the building energy efficiency level, the RTQ-C assesses three individual systems: envelope, lighting system and air conditioning system, considering weights of 30%, 30% and 40%, respectively. A partial (envelope, envelope and lighting, envelope and air conditioning) or general label can be conceded to the building, in which the three systems were evaluated, resulting in a final classification. The classification always ranges from A (most efficient) to E (less efficient).

The project assessment is realized through two methods: the prescriptive method, which is a simplified method, and the simulation method. The prescriptive method was developed using the statistical method of multiple linear regression.

In the prescriptive method, the numerical equivalents for the envelope, lighting and air conditioning are calculated, considering artificial conditioned environments for areas of prolonged permanence. The envelopes consume indicator (IC_{env}) is found by equations determined according to the bioclimatic zone, in which the project is settled. For each bioclimatic zone, there are two different equations, one for buildings with a projected area (A_{pe}) smaller than 500 m^2 and another for buildings with a projected area bigger than 500 m^2.

The RTQ-C presents maximum limits of thermal transmittance for walls and roofs according to the energy efficiency level and the bioclimatic zone in which the building is located. Those limits, however, do not take into consideration the possibility for occupation and heat generation. The regulation makes observations regarding the ILD (internal load density) only for an artificial lighting scenario.

It is common sense that as higher the wall thermal resistance as better is the thermal energy performance of the building. However, some works show that, for office buildings, this analysis depends on other variables, like the climate and the internal load density of the building. According to Westphal [3], for an office-building model in Curitiba City, with the internal load density about 20 W/m^2, low external thermal absorbance, and occupancy pattern about 8 h/day, the increase of thermal transmittance increases the air conditioning energy consumption. However, in the same building with internal load density of 50 W/m^2, a energy consumption decrease is observed, considering the HVAC when the envelope has higher thermal transmittance. Melo [4] showed that the internal load density increases, and the impact of the HVAC energy consumption increases, too. However, if the thermal transmittance of the walls is increased, the internal heat dissipations is easy. As a result, we have lower consumption observing the Curitiba and Florianópolis climate in Brazil.

Chvatal [5] held a study that aimed to analyze the impact of the envelope thermal insulation of the buildings in the thermal performance, observing the tropical climates. It was observed that the heat losses in the building for the insulated envelop become difficult and the internal temperature increases. In this study, it was possible to observe that the thermal discomfort in summer is high due to the high internal load of equipment and occupancy occurs during the same period of the maximal solar gains.

Considering the importance of those researches and the limitation of the Brazilian Energy Efficiency Regulation (RTQ-C, prescriptive method) that uses only 25 W/m^2 as internal load density to the developing of the linear regression equations, it was decided to analyze the sensibility of the RTQ-C to the internal load density variation. Two Brazilian bioclimatic zones were chosen to analyze the sensibility of the prescriptive method of RTQ-C, Zones 1 and 7. Zone 1 is the coldest one of the country. The average temperatures are under 20 °C, and the annual thermal amplitude is between 9 °C and 13 °C. Bioclimatic Zone 7 is characterized by tropical and wet climate, presenting concentrated rains period since October until April. Between May and September, the dry air mass over the center of the country minimizes the rainy formation. The maximum temperatures can reach 40 °C in the warmer months, and in the coldest, the average of the minimal is 16.6 °C.

2. Method

The method employed to reach the objective of this paper is divided into five stages, which are presented as follows: analysis models definition; ILD assessment, to be used in the configuration of the analysis models; determination of analysis models envelopes according to RTQ-C, energy consumption determination on the evaluated models; comparison of consumption in buildings with envelopes Level A, Level B or Level C, with different equipment internal load density.

2.1 Determination of the Analysis Models

For this study, five different analysis models were defined. The first analyzed model was defined based on the study developed by Carlo [6]. The author, through a photographic survey in five Brazilian cities, was able to observe typical volumetries, more frequent in the urban landscape, destined to some commercial activities. Through the survey, it was possible to generate a representative model for each activity. The first defined model was identified by the author with the "big offices" name and characterized as a vertical edification, with floor area smaller than 500 m^2, having five floors, rectangular shape, with dimensions of 27-m length, 7.8-m width and 15-m height. Fig. 1 illustrates the "big offices" model.

The other analyzed models were determined with basis on the equations from RTQ-C, which defines limits for a minimal shape factor and a maximum shape factor. The shape factor is determined by the ratio between the envelope area and the total volume of the building. The RTQ-C establishes for bioclimatic Zones 1 and 7, with a minimal shape factor of 0.17 for buildings with a projected area bigger than 500 m^2 and the maximum shape factor of 0.60 for buildings with a projected area smaller than 500 m^2. For each shape factor (minimal and maximal), two models were defined with the intention of assessing the differences between a larger roof area against a larger wall area. Thus, Models 1 and 2 (Figs. 2 and 3), with the minimal shape factor, show 10 and 2 floors, respectively. The Models 3 and 4 (Figs. 4 and 5), with maximal shape factor, possess 10 and 1 floors, respectively. The volumetric characteristics for each model can be observed in Table 1, as follows.

2.2 Characterization of the Internal Load Density to Be Used in the Configuration of the Analysis Models

The ILD is defined by the sum total of the three main internal sources of heat: lighting, electrical appliances and human beings. The lighting system of the models was configured with the lighting potency density of 10 W/m^2. RTQ-C classifies the lighting system for office buildings as Level A, with a limit potency of 9.7 W/m^2.

Fig. 1 The "big offices" model.

Fig. 2 Model 1.

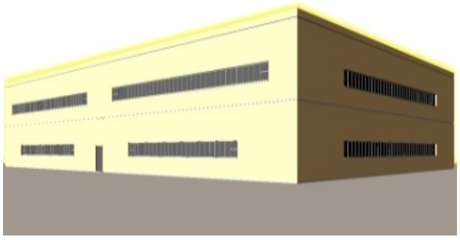


Fig. 3 Model 2.

Fig. 4 Model 3.

Fig. 5 Model 4.

Table 1 Volumetric characteristics of models based on RTQ-C.

Variables	Minimal shape factor		Maximal shape factor	
	Model 1	Model 2	Model 3	Model 4
Dimensions	35 m × 25 m	70 m × 45 m	10 m × 6m	27 m × 7.5 m
Height	30 m	10 m	30 m	4 m
Floor area	875 m^2	3,150 m^2	60 m	211 m^2
Total area	8,750 m^2	6,300 m^2	600 m^2	211 m^2
Shape factor	0.17	0.17	0.60	0.60
Height factor	0.10	0.50	0.10	1.00
Number of floors	10.00	2.00	10.00	1.00

However, the DesignBuilder software allows only for the use of round numbers, this being the reason the value was rounded up to 10 W/m^2. The air conditioning system of the models was considered as a split type, with a COP (performance coefficient) of 3.21, considered Level A in the RTQ-C.

The ASHRAE Fundamentals [7] standard classifies the offices in four types of appliances internal load density. In this paper, only two types of density were observed: medium and high. Table 2 characterizes the adopted values according to the ASHRAE Fundamentals [7] standards for appliances internal load density, NBR 16.401—Part 3 [8] person density and RTQ-C [9] for lighting potency density.

Table 2 Characterization of the internal load densities used in the analysis models.

Office type	ILD appliances (W/m^2)	Person density ($person/m^2$)	Lighting potency density (W/m^2)
Medium density	11	0.14	10
High density	21	0.20	10

Table 3 Envelope prerequisites for bioclimatic Zone 1.

Envelope prerequisites	Level A	Level B	Level C
Thermal transmittance roof	0.5 $W/m^2 \cdot K$	1.0 $W/m^2 \cdot K$	2.0 $W/m^2 \cdot K$
Thermal transmittance external wall	1.0 $W/m^2 \cdot K$	2.0 $W/m^2 \cdot K$	3.7 $W/m^2 \cdot K$
Roof absorptance	0.20	0.20	0.20
External wall absorptance	0.20	0.20	0.20

Table 4 Envelope prerequisites for bioclimatic Zone 7.

Prerequisite	Wall	Roof	Absorptance
Level A	W1: $U = 2.50\ W/m^2 \cdot K$ and max$CT = 80\ KJ/m^2 \cdot K$	$U = 1.00\ W/m^2 \cdot K$	Roof: $\alpha < 0.50$
	W2: $U = 3.7\ W/m^2 \cdot K$ and $CT > 80\ KJ/m^2 \cdot K$	-	Wall: $\alpha < 0.50$
Level B	W1: $U = 2.50\ W/m^2 \cdot K$ and max$CT = 80\ KJ/m^2 \cdot K$	$U = 1.50\ W/m^2 \cdot K$	Roof: $\alpha < 0.50$
	W2: $U = 3.7\ W/m^2 \cdot K$ and $CT > 80\ KJ/m^2 \cdot K$	-	Wall: without prerequisite
Level C	W1: $U = 2.50\ W/m^2 \cdot K$ and max$CT = 80\ KJ/m^2 \cdot K$	$U = 2.00\ W/m^2 \cdot K$	Roof: without prerequisite
	W2: $U = 3.7\ W/m^2 \cdot K$ and $CT > 80\ KJ/m^2 \cdot K$	-	Wall: without prerequisite

W1 means Wall 1; W2 means Wall 2.

Table 5 Parameters used in the analysis models.

Parameters	Adopted values
Use pattern (h/day) (occupancy, appliance and lighting) (Saturdays and Sundays were not considered as occupancy periods)	From 08:00 a.m. to 12:00 a.m.—100% From 12:00 a.m. to 02:00 p.m.—10% 02:00 p.m. to 06:00 p.m.—100%
Air conditioning system's performance coefficient (W/W)	3.21 W/W for heating and cooling
Heating setpoint (°C)	18
Cooling setpoint (°C)	24
Orientation of major frontage	North/south

2.3 Determination of the Building Envelope Characteristics

RTQ-C determines that the thermal transmittance of external walls and roofs and their absorptance, are specific prerequisites of the envelope. These prerequisites have limits established for each bioclimatic zone, regarding the level of intended energy efficiency. In this paper, models walls and roofs were configured with the thermal characteristics according to the prerequisites for bioclimatic Zones 1 and 7, as shown on Tables 3 and 4, respectively. The absorptance was considered constant at 0.20 in both analyzed bioclimatic zones. Bioclimatic Zone 7 allows for two different wall configurations, so each model was configured two times, one with each wall type.

2.4 Determination of Energy Consumption in Models with Characteristics According to Different RTQ-C Levels for Energy Efficiency

In order to obtain the energy consumption from buildings with characteristics according to the different energy efficiency levels proposed on RTQ-C, simulation were made through the DesignBuilder software, version 3.0.0.15. First, the "PR_Curitiba.epw" weather file was configured for the city of Curitiba, bioclimatic Zone 1, and the "MT_Cuiaba.epw" file was configured for the city of Cuiaba, bioclimatic Zone 7. After modeling the buildings in the software, the parameters used in the energy modeling were informed, as visible in Table 5.

2.5 Comparison between Consumption in Buildings with Levels A, B and C and Envelopes with Different Appliances Internal Load Densities

Through the energy modeling, the yearly energy consumption rate for each model was obtained. These data made it possible to assess and compare the energy performance for the different envelope configurations according to the RTQ-C. The Level A model presents a limit for the frontage's opening percentage lower to that on the Levels B and C models, therefore, a comparison was made between the Level A model with maximum WWR (window to wall ratio) of 0.15 with Model 2, with maximum WWR of 0.10. On the other WWRs, the analysis between Levels B and C models was made. Results are shown as comparative analysis of the diverse simulations made in a table form.

3. Results Analysis

The results analysis is divided in two parts: The first part shows results for bioclimatic Zone 1 and the second part shows the results for bioclimatic Zone 7.

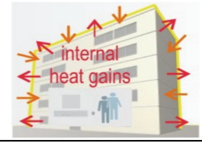
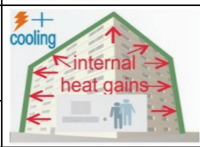
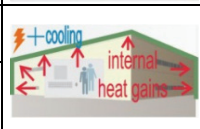
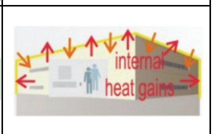
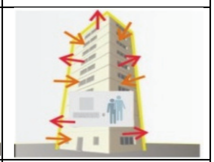
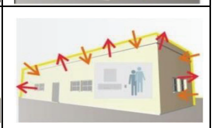
3.1 Bioclimatic Zone 1

In Table 6, the results found for bioclimatic Zone 1 can be observed, after which there would be the analysis of the results.

3.1.1 "Big Offices" Model

In the equipment ILD, it was possible to observe the buildings envelope, meeting the prerequisites for Level A presented as a higher energy consumption by comparison with the others, mainly due to the fact that this envelope is more insulated, preventing the heat exchange from the inside with the outside. As for the

Table 6 Results for bioclimatic Zone 1.

Energy modeling results for bioclimatic Zone 1													
Energy efficiency		Medium ILD					High ILD					Influence of internal load density in the envelope of energy performance according to the levels of energy efficiency	
		WWR					WWR						
		0.05	0.10	0.15	0.20	0.25	0.05	0.10	0.15	0.20	0.25	Model A	Model C
Model "big office"	+ ⇧	B	B	B	C	C	C	C	C	C	C		
	− ⬇	A	A	A	B	B	A	A	A	B	B		
Model 1	+ ⇧	C	C	C	C	C	C	C	C	C	C		
	− ⬇	A	A	A	B	B	A	A	A	B	B		
Model 2	+ ⇧	C	C	C	C	C	C	C	C	C	C		
	− ⬇	A	A	A	B	B	A	A	A	B	B		
Model 3	+ ⇧	B	B	B	C	C	C	C	C	C	C		
	− ⬇	C	A	A	B	B	A	A	A	B	B		
Model 4	+ ⇧	A	A	-	-	-	B	B	-	-	-		
	− ⬇	C	C	-	-	-	C	A	-	-	-		

+ ⇧: More energy efficient model;

− ⬇: Less energy efficient model.

Level B model, the smallest energy consumption is showed until the WWR = 0.15. Observing the results of the heat exchanges between components of the building, it can be concluded that Level C has shown the largest heat losses in walls, covertures and roofs, while in Level B, the same occurred trough glasses, ground floor and infiltration. Starting from WWR = 0.20, the Level C presents smaller energy consumption by a small difference (67 kWh). Both Levels B and C models decreased their heating consumption from WWR 0.20 to WWR 0.15, and have increased their cooling. Level C, however, by having a higher thermal transmittance, allows a bigger exchange with the outside environment, thus needing a smaller energy consumption for cooling, therefore, showing a smaller overall energy consumption.

As for the influence of ILD in the results, it can be assessed that, with the increase in ILD, Level C showed the smallest energy consumption amongst all WWRs. With the increase in internal heat, the better insulated buildings (Levels A and B) need a higher use of an air conditioning system for cooling, since they do not make it difficult for the internal heat to dissipate to the outside environment.

3.1.2 Model 1

In Model 1, with minimal shape factor and 10 floors, models that presented a higher thermal insulation (Level A) in its envelope showed a higher energy consumption when compared with the models of higher thermal transmittance (Levels B and C). One can observe that the models with the envelope meeting the Level C prerequisites have obtained the best energy performance on both analyzed ILDs. Assessing the thermal gains in buildings, it is possible to assess that the models configured for Level C show bigger heat losses through walls, roofs and ground. Therefore, Level C models show higher energy consumption for heating, while the Levels A and B models need higher energy consumption for cooling, thus bringing the higher overall energy consumption rate.

3.1.3 Model 2

In Model 2, with minimal shape factor and two floors, it was possible to observe that in both equipment densities analyzed (11 W/m^2 and 21 W/m^2), the ones presenting a higher thermal insulation in its envelops (Level A) have showed higher energy consumption compared to those buildings with higher thermal transmittance (Levels B and C). As seen before in the other models, this fact occurs due to overheating in the inside of the building, caused by the thermal insulation not allowing for internal heat to dissipate in the outside environment. Therefore, the Level C model presenting the higher thermal transmittance value showed the best thermal performance.

It was possible to observe that in both models with shape factor (Models 1 and 2) that presented area bigger than 500 m^2, the increase of the internal load density did not change the simulation results. It was possible to realize that even in the medium ILD, the Level A model already presented overheating, occurring the biggest energy consumption regards to energy Levels A and B.

3.1.4 Model 3

In Model 3, with maximum shape factor and 10 floors, average ILD of equipments (11 W/m^2), it could be observed that, as the opening percent of the frontage changed, the results were also modified. In WWR = 0.05, Level C model presented the higher energy consumption and a difference of 459 kWh from the Level A model. The Level C model, having the biggest heat losses through envelopment (roof and walls), needing a higher energy consumption for heating, thus consuming more energy than the other level models. Starting with WWR = 0.10, with the increase in heat gains through radiation, the Level A models start to consume more energy. This happens due to overheating caused by the envelope’s insulation, which prevents heat from dissipating to the outside of the building. Therefore, Level A models showed higher energy consumption for cooling, and as a consequence, they consume more energy than the remaining

Levels B and C. As for the Level B models, they are the ones that showed the best energy performance for WWR up to 0.15, due to their capacity to keep milder internal temperatures, not needing much energy neither for heating or cooling. From WWR = 0.20 onward, when the radiation heat gains increase, the Level B models need higher energy consumption for cooling, which brings a higher energy consumption when compared with Level C models.

With the increase in ILD, the Level C models presented the best energy performance. As previously noted, the Level C models, showing a higher thermal transmittance, allow for a larger heat exchange with the outside environment, thus allowing the heat generated by the increase in equipments to dissipate outside, needing a smaller energy consumption for cooling. As for the more insulated models (Levels A and B), they end up generating overheat in the inside of the building, which brings a higher use of the cooling system and by consequence a higher energy consumption.

3.1.5 Model 4

In Model 4, with maximum shape factor and one floor and with average equipment ILD (11 W/m^2), buildings with the envelope meeting the prerequisites for Level A showed the lowest energy consumption. It was possible to observe that the Level A models had a larger heat loss through glass, ground floor and infiltration. As for the Level C models, the heat loss was through walls and roof, as expected, due to these buildings having higher thermal transmittance in those elements. Therefore, by allowing a larger heat exchange with the outside environment, the Level C models showed the higher energy consumption both for cooling and heating, thus bringing the larger energy consumption when compared with other levels.

Analyzing the same model with a high ILD (21 W/m^2), the found results are different. In the model with WWR = 0.05, Level C model presented the higher energy consumption, while the Level B model had the lowest one. This is because Level C model presents a higher energy consumption for heating, once it presents higher heat losses through walls and roof in comparison with other levels models. Level A model, in turn, presents a higher consumption for cooling, since it presents the lowest heat losses through walls and roof, keeping the ambience overheated. Therefore, Level B model, less insulated than the Level A one, presented the best result, since it needs lower energy consumption for cooling and heating.

As for WWR = 0.10, Level A model presented the highest energy consumption. With the opening increase, the radiation heat gains also increased, which when added to the internal heat generated by equipment and brought the increase in overheating. Therefore, the model needed higher energy consumption for cooling, thus consuming more energy than Level C model.

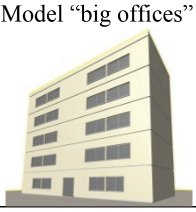
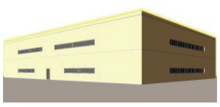
3.2 Bioclimatic Zone 7 Results

In Table 7, the results for bioclimatic Zone 7 can be found. Next, there is the results analysis.

3.2.1 “Big Offices” Models

In the medium equipment ILD energy modeling, it can be observed in Wall 1 (W1) that the envelope meeting the Level A prerequisites presented a higher energy consumption comparing to the others. This is justified by the higher energy consumption needed for cooling, due to the presence of a more thermal insulated envelope than that in the remaining models (Levels B and C). The Level C envelope presented the lowest energy consumption; The Level B model needs higher energy consumption for cooling the Level C model. In the results found with the high equipment ILD, Level A model also presented the highest energy consumption. As for the Level C models, they present the lowest consumption up to WWR = 0.10. After that, Level B models are the ones presenting the lowest energy consumption. With the increase in LID causing increase in internal heat, the Level C models, having higher thermal transmittance, allow for a larger heat loss when comparing with other models. However, with WWR = 0.10 and onward, the Level C models need

Table 7 Bioclimatic Zone 7 results.

Energy modeling results for bioclimatic Zone 7												
Models	Wall	Energy efficiency	Medium ILD					High ILD				
			WWR					WWR				
			0.05	0.10	0.15	0.20	0.25	0.05	0.10	0.15	0.20	0.25
Model "big offices" 	W1	+ ⇧	C	C	C	C	C	C	C	B	B	B
		− ⬇	A	A	A	B	B	A	A	A	C	C
	W2	+ ⇧	C	B	B	B	B	C	B	B	B	B
		− ⬇	A	A	C	C	C	A	A	C	C	C
Model 1 	W1	+ ⇧	C	C	C	C	C	C	C	C	C	C
		− ⬇	A	A	A	B	B	A	A	A	B	B
	W2	+ ⇧	C	C	C	C	C	C	C	C	C	C
		− ⬇	A	A	A	B	B	A	A	A	B	B
Model 2 	W1	+ ⇧	C	C	C	C	C	C	C	C	C	C
		− ⬇	A	A	A	B	B	A	A	A	B	B
	W2	+ ⇧	C	C	C	C	C	C	C	C	C	C
		− ⬇	A	A	A	B	B	A	A	A	B	B
Model 3 	W1	+ ⇧	C	C	C	C	C	C	C	C	C	C
		− ⬇	A	A	A	B	B	A	A	A	B	B
	W2	+ ⇧	C	C	C	C	C	C	C	C	C	C
		− ⬇	A	A	A	B	B	A	A	A	B	B
Model 4 	W1	+ ⇧	A	B	-	-	-	B	C	-	-	-
		− ⬇	C	C	-	-	-	C	A	-	-	-
	W2	+ ⇧	B	C	-	-	-	C	C	-	-	-
		− ⬇	A	A	-	-	-	A	A	-	-	-

W1—Wall 1: $U = 2.5$ W/ m^2·K, CT is maximum about 80 KJ/m^2·K;
W1—Wall 1: $U = 3.7$ W/ m^2·K, $CT > 80$ KJ/m^2·K;
+ ⇧: More energy efficient model;
− ⬇: Less energy efficient model.

a higher energy consumption for cooling and heating when compared to the Level B model.

In the office model, with Wall 2 (W2) ($U = 3.7$ W/m^2·K, $CT > 80$ KJ/m^2·K), the results were a little different from those with Wall 1 (W1). The Level A model presented the highest energy consumption with WWR up to 0.10, value after which the Level C model showed the highest energy consumption. As for the Level B model, it presented the lowest energy consumption amongst all analyzed WWRs, with the exception of WWR = 0.05, with which the Level C model presented the best energy consumption level. These results were equal to the ones for the other two analyzed ILDs. Observing the results for WWRs = 0.05, the Level C model presents the higher heat loss through envelope, therefore, presenting a lower energy consumption for cooling than the models Levels A and B. From WWR = 0.10 onwards, the Level B model presents the higher heat losses through envelope. It also presents lower energy consumption than that of Level C model (56 kWh). With high ILD, the same fact occurs for Level C model, which presents the highest heat loss through envelope only for WWR = 0.05, therefore, needing a lower energy consumption for cooling. In the subsequent WWRs, the Level B model presents the higher heat loss through envelope. Level C models, starting from WWR = 0.15, because they increase their radiation gains and present a higher thermal transmittance in the roof, begin to need a higher consumption for cooling and heating, thus presenting the higher energy consumption.

Assessing the behavior of wall, with medium ILD, Wall 2 (W2) presented the higher energy consumption with WWR = 0.05 for all levels (Levels A, B and C) when compared to Wall 1 (W1). With the increase in WWR, Wall 1 (W1) needs a higher energy consumption for cooling, which causes higher energy consumption in comparison with Wall 2 (W2). With WWR = 0.05, the envelope configured with Wall 1 (W1) shows higher heat losses than the envelope configured with Wall 2 (W2). Therefore, the model with Wall 2 needs a higher consumption for cooling if compared with Wall 1 (W1), and consequently, they present higher energy consumption. With the increase of the radiation gains, the internal heat also increases and, since Wall 2 (W2) presents higher thermal transmittance, it allows for the heat to dissipate in the external environment, needing less consumption for cooling and presenting lower energy consumption than Wall 1 (W1). With the increase in ILD, and the increase in internal heat, Wall 2 (W2) shows the lower consumption precisely because it needs a lower consumption for cooling.

3.2.2 Model 1

In Model 1, with minimum shape factor and 10 floors, the models that presented higher insulation in its coverings (Level A) showed a higher energy consumption compared to the models with higher thermal transmittance in its coverings (Levels B and C) on both analyzed ILD (11 W/m^2 and 21 W/m^2). The Level A models presented the higher heat losses through glass and walls, however, they still presented a large amount of heat stored in their insides, due to thermal insulation of the covering. This way, the need for cooling was higher when compared to other energy efficiency levels. As for the Level C models, they presented the higher heat losses through roof, coverture and floor, and they also presented the lower energy consumption for cooling. Bioclimatic Zone 7 presents high temperatures, so there was no need for heating in any of the models assessed. This way, the Level C models showed lower energy consumption. The increase in ILD did not influence the results, once, since the medium ILD, the Level A models presented high temperatures, needing a higher consumption for cooling. However, in high ILD (21 W/m^2), the difference in results between the energy efficiency levels was higher. In medium ILD (11 W/m^2), WWR = 0.15, the Level A model presented 1,870 kWh/year more than the Level C model, as for the high ILD (21 W/m^2), the yearly difference was 2,330 kWh.

In Model 1, with Wall 2 (W2) (U = 3.7 W/m^2·K, CT > 80 KJ/m^2·K), the results were the same as the ones for Wall 1 (W1). Level A presented the highest energy consumption and Level C presented the lowest. The models with Wall 1 (W1) (U = 2.50 W/m^2·K, CT is maximum about 80 KJ/m^2·K), however, presented higher energy consumption than those with Wall 2 (W2). With medium ILD for Level A model, WWR = 0.015, presenting the largest difference in yearly consumption: 6,760 kWh. This result was influenced by the fact that Wall 2 (W2) presented a higher heat loss through walls and, therefore, needed lower energy consumption for cooling, thus presenting lower energy consumption. In high ILD, the differences in consumption between Wall 1 (W1) and

Wall 2 (W2) were higher, the highest one with Level A models and with WWR = 0.15, in which Wall 1 (W1) presented energy consumption 10.330 kWh higher than Wall 2 (W2). This happens due to the increase in internal heat, Wall 1 (W1) presenting lower thermal transmittance than Wall 2 (W2).

3.2.3 Model 2

In Model 2, with minimum shape factor and two floors, it was possible to observe on both equipments ILDs (11 W/m^2 and 21W/m^2), as well as in both analyzed walls that the models presenting higher thermal insulation in their envelope (Level A), presented higher energy consumption when compared to the models with higher thermal transmittance (Levels B and C). Model 2 presents a large area of coverture (3.150 m^2), this way, even in the models with medium ILD, they presented need for energy consumption for cooling, specially the Level A model. Said model presents overheating due to having a more insulated roof, therefore, needing higher consumption for cooling when compared to models from other levels. This justifies why the ILD did not influence the results. Although having no influence in the results, the increase in ILD brought a higher difference in energy consumption between Levels A, B and C. In Wall 1 (W1), WWR = 0.15, medium ILD, the Level A model presented 4.860 kWh more than the Level C model, which presented the lowest energy consumption. As for high ILD, this difference changes to 16.880 kWh.

Regarding the difference between walls, with medium ILD (11 W/m^2), Wall 1 (W1) (U = 2.50 W/m^2·K, CT is maximum about 80 KJ/m^2·K) presents lower energy consumption, while with high ILD, Wall 2 (W2) (U = 3.7 W/m^2·K, CT > 80 KJ/m^2·K) presents lower energy consumption. On both analyzed ILDs, Wall 2 (W2) loses more heat than Wall 1 (W1), because it presents higher thermal transmittance, which allows for a larger heat exchange with the environment. However, in medium ILD, analyzing all the elements (glass, walls, roof, floors and infiltration), models with Wall 1 (W1) lose more heat than models with Wall 2 (W2), therefore, models with Wall 2 (W2) need a higher consumption for cooling and thus consume more energy. As for high ILD, the difference in heat loss through walls results increases, this way, models configured with Wall 2 (W2) need lower energy consumption for cooling and consequently consume less energy. In this ILD, the larger difference in loss heat between Walls 1 and 2 was 16.160 kWh with WWR = 0.15, Level A.

3.2.4 Model 3, Bioclimatic Zone 7

In Model 3, with maximum shape factor and 10 floors, ILD did not influence the results. In both analyzed ILDs (11 W/m^2 and 21 W/m^2), Level A model presented higher energy consumption and Level C model presented the best energy performance, with all WWRs analyzed. And this result was equal on both analyzed walls. This result can be explained by the same fact that occurred in Model 2, an overheating in Level A models, creating the need for cooling. As an example, in medium ILD, WWR = 0.15, Level A model presented energy consumption 43 kWh and 104 kWh higher than models Levels B and C, respectively, and 51 kWh and 123 kWh in high ILD for the same WWR. Bioclimatic Zone 7 presents elevated temperatures, this way, the Level A model, presenting more insulated roof that causes overheating inside the building, which can be observed since medium ILD as well. In high ILD, with the increase in internal heat, the overheating in Level A models becomes more noticeable, presenting higher difference in energy consumption when compared to other levels models (Levels B and C).

Regarding the energy efficiency of walls, it was possible to observe that Wall 1 (W1) presented higher energy consumption, lower only for models with medium ILD, WWR = 0.05, for all levels studied (Levels A, B and C). With increase in the frontage opening percentage, Wall 2 (W2) presents the best performance, as well as in models with high ILD. Wall 1 (W1), presenting lower thermal transmittance, exchanges less internal heat with the outside environment and with the increase in openings, which increase the radiation gains, Wall 1 (W1) needs higher energy consumption for cooling, when compared to Wall 2 (W2). With high ILD, which increases internal heat, Wall 2 (W2) presents higher thermal transmittance allowing for a larger exchange with the outside and, once again, presents a smaller need for cooling, thus presenting lower energy consumption than Wall 1 (W1).

3.2.5 Model 4

In Model 4, with maximum shape factor and one floor, with medium equipment ILD (11 W/m^2), the models with envelopes meeting the prerequisites for Level C presented the higher consumption level for Wall 1 (W1). This is due to the fact that the Level C model is losing less heat than models from other levels (Levels A and B), the difference being greater than 807 kWh with WWR 0.10 when compared to Level A. It was also possible to observe that the Level C model presents a higher heat loss through roof, although it loses less heat through walls when compared with the Levels A and B models. This way, the Level C model presented the highest energy consumption for heating and cooling due to presenting a higher thermal transmittance and allowing a larger heat exchange with the outside environment. Level A presented the lower consumption with WWR = 0.05, as for WWR = 0.10, Level B presented the lower consumption. This difference is due to the fact that with the increase in openings the models gain more heat through radiation, which brings an increase in energy consumption for cooling, while the Level A model, presenting more insulated roof, kept more internal heat, needing higher energy consumption when compared to Level B model.

With the increase in ILD (21 W/m^2), the results presented a small difference. Level B presented the lowest energy consumption with WWR = 0.05 and Level C did the same with WWR = 0.10. Level C presented the highest energy consumption with WWR = 0.05, and Level A did the same with WWR = 0.10. With WWR = 0.05, Level C presents higher energy consumption for heating and cooling, when compared to other levels (Levels A and B). This is due to the fact that the roof presents higher thermal transmittance. As for WWR = 0.10, with the increase in solar radiation gains, the level C model presents the lowest energy consumption for cooling, and Level A presents the highest, due to presenting more insulated roof, keeping internal heat. It should be noted that the differences between levels were small. Level A presented energy consumption of 16.554 kWh/year, Level B had 16.520 kWh/year and Level C 16.514 kWh/year.

Regarding the walls, it can be observed that they influenced the results. In Wall 2 (W2), the Level A models presented the highest energy consumption on both analyzed ILDs (11 W/m^2 and 21 W/m^2), and Level C presented the lowest energy consumption, with the sole exception of WWR = 0.05, medium ILD, in which Level B presented the best energy performance. It was possible to observe that, with WWR = 0.05, Wall 2 (W2), presenting a higher transmittance gained much more heat when compared with Wall 1 (W1), the difference being 2.889 kWh. This way, the Level A model of Wall 2 (W2) consumes more energy for cooling. In the models with Wall 2 (W2), Level A presents higher energy consumption, because Wall 2 (W2) has bigger thermal transmittance value than Wall 1 (W1). This way, heat enters into the building with Level A roof, and building with a higher insulation compared to other levels (Levels B and C), needs higher consumption for cooling. As for Wall 1 (W1), in which the transmittance is lower, the Level C model, because it presents higher transmittance in its roof, presents the higher energy consumption, needing cooling and heating for the edification. However, with high ILD and WWR = 0.10, Level A model presents the highest consumption. In this case, the internal heat gains added to the increase in gains through radiation increased the need for cooling, and Level A model, showing the more insulated roof, presented the worst performance. Since this model is a one floor only model, the roof has a higher influence over results than in the remaining models.

4. Conclusions

This paper has shown that buildings with high ILD and a higher thermal insulation envelope may obtain higher energy consumption. It was observed that for bioclimatic Zone 1, the building with walls and roof configured to meet the prerequisites for Level C (walls and roof thermal transmittance) presents lower consumption when compared with the envelope meeting Level A requirements.

It was also possible to observe that in both models with minimum shape factor and area larger than 500 m^2, the increase in ILD did not alter the results. It can be observed that even with medium ILD, the Level A model already presents overheating, creating higher energy consumption when compared to models from other levels (Levels B and C). As for the models with area smaller than 500 m^2, the increase in ILD did influence the results.

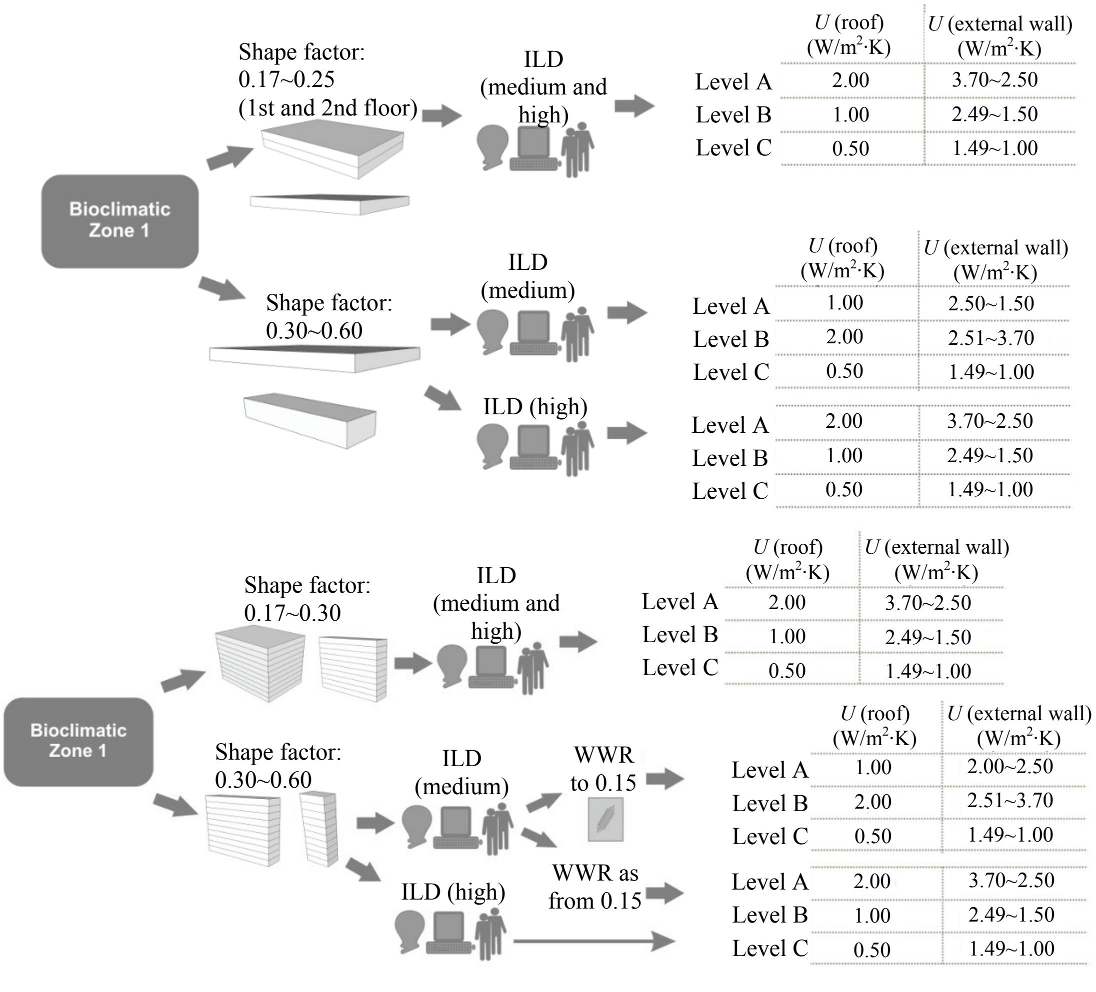


Fig. 6 Bioclimatic Zone 1 results.

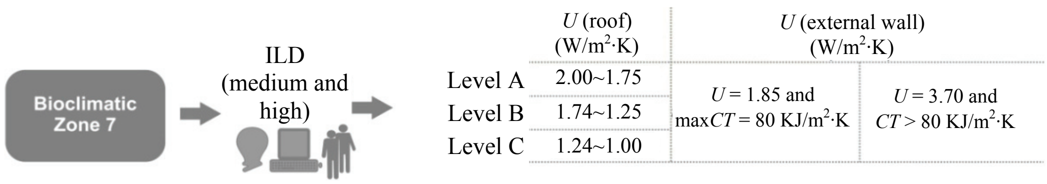


Fig. 7 Bioclimatic Zone 7 results.

In bioclimatic Zone 7, the ILD influenced two models only: the offices building and Model 2. Since, for bioclimatic Zone 7, the only factor considered is the roof insulation, the changes in ILD did not influence much. However, it was possible to observe that both models configured for Level A presented higher energy consumption, because they present overheating even in medium ILD, the same happening in bioclimatic Zone 1.

Regarding the employed walls, in bioclimatic Zone 7, it was possible to verify that Wall 2 (W2) (U = 3.7 W/m^2·K, CT > 80 KJ/m^2·K) presents better performance in high ILDs, since it needs less energy consumption for cooling, because it presents higher thermal transmittance and allows the internal heat to dissipate outside. As for Wall 1 (W1) (U = 2.50 W/m^2·K, CT is maximum about 80 KJ/m^2·K), it presents the best performance for medium ILD, WWR = 0.05 and in buildings of one or two floors. With WWR = 0.05, Wall 2 (W2) needs higher consumption for cooling when compared with Wall 1 (W1). As for Model 2, with minimal shape factor and two floors, Wall 1 (W1) presented the best performance since it needs less energy consumption for cooling.

The work done emphasizes the importance of the analysis of the internal load density variation observing other building variables, as it was shown in another presented researches. Pino et al. [10] developed a work where the results defined that for the Santiago do Chile climate with low cloudiness during the spring, and in the summer, it can happen overheating in office buildings. This phenomenon occurs in the most of the buildings with large WWR in facades and without solar protection [10]. In the realized work by Melo [4], the results showed that high buildings with high ILD (70 W/m^2) combined with lower solar absorptance of external surfaces the increase of the thermal transmittance of the walls results a decrease of the energy consumption observing the Brazilian cities of Florianópolis, Curitiba e São Luis [4].

According to the results obtained from different configurations, observing the specifics requirements of the RTQ-C, thermal transmittance values of walls and roofs were indicated, considering also different ILD and bioclimatic zones. These values are presented in Figs. 6 and 7. The work contribution is defined by the classification of the thermal transmittance for the different levels of energy efficiency considering WWR, ILD and shape factor.

References

[1] Official Gazette. 2001. *Law No. 10295 of 17 October 2001: About the National Policy for Conservation and Rational Use of Energy.* Brasilia: Official Gazette. (in Portuguese)

[2] Official Gazette. 2001. *Decree No. 4059 of 19 December 2001.* Brasilia: Official Gazette. (in Portuguese)

[3] Westphal, F. 2007. “Analysis of the Uncertainty and Sensitivity Applied to the Simulation of Energy Performance of Commercial Buildings.” M.Sc. thesis, Postgraduate Program in Civil Engineering, Federal University of Santa Catarina, Florianopolis. (in Portuguese)

[4] Melo, A. P. 2007. “Analysis of the Influence of Thermal Transmittance Coefficient in Energy Consumption of Commercial Buildings.” M.Sc. thesis, Postgraduate Program in Civil Engineering, Federal University of Santa Catarina, Florianopolis. (in Portuguese)

[5] Chvatal, K. 2007. “Relationship between Thermal Insulation Level of the Surroundings of Buildings and Potential Overheating in Summer.” Ph.D. thesis, Engineering Sciences Department, University of Porto. (in Portuguese)

[6] Carlo, J. 2008. “Development of Energy Efficiency Assessment Methodology for Envelopes of Nonresidential Buildings.” Ph.D. thesis, Graduate Program in Civil Engineering, Federal University of Santa Catarina, Florianópolis. (in Portuguese)

[7] ASHRAE (American Society of Heating, Refrigerating and Airconditioning Engineers). 2009. *ASHRAE Handbook—Fundamentals.* Atlanta: ASHRAE, 9-19.

[8] ABNT (Brazilian Association of Technical Standards). 2008. *NBR 16.401: Installation of Air Conditioning—Central and Unitary Systems. Part 3: Indoor Air Quality.* Rio de Janeiro: ABNT. (in Portuguese)

[9] INMETRO (National Institute of Metrology, Standardization and Industrial Quality). 2013. *Quality Technical Standards for Energy Efficiency Level in*

Commercial and Public Services Buildings. Brasília: Eletrobras. (in Portuguese)

[10] Pino, A.. Bustamante, W., Escobar, R., and Pino, F. 2012. "Thermal and Lighting Behavior of Office Buildings in Santiago of Chile." *Energy and Buildings, Elsevier* 47: 441-9. Accessed November 1, 2013. http://www.sciencedirect.com/science/article/pii/S0378778811006268.