

Article

Characterization of Representative Residential Buildings within a Neighborhood and Their Energy Efficiency Levels According to RTQ-R

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Abstract: Approximately 54% of Brazilian electricity consumption is attributed to the residential, commercial, public, and service sectors; thus, it is important to formulate strategies that promote both the energy efficiency of buildings and a better understanding of their thermal and energy performance. Within the scope of the Brazilian Labeling Program (Programa Brasileiro de Etiquetagem—PBE), technical regulations were developed to classify the level of energy efficiency of buildings. This article defines four representative buildings based on an analysis of the most common typologies that represent the multi-family residential buildings of a neighborhood. A total of 663 buildings were mapped and classified. The four representative buildings were evaluated for their thermal and energy performance in relation to Building Labeling (Quality Technical Regulation—Residential: RTQ-R). The results for the housing units (HUs) were analyzed for cooling degree-hours (cooling for summer), relative consumption for refrigeration (artificial cooling), performance of the envelope in summer, and the final classification of the HUs by the water heating system; the results for the entire multi-family building were analyzed. These results provide data that will contribute to an efficient policy for the housing industry and to future studies on the incorporation of measures that promote energy efficiency.

Keywords: sustainable built; building regulation; energy performance; energy efficiency; economy in residential buildings

1. Introduction

Electrical Energy is also used in buildings to control the internal temperature, ventilation, lighting, equipment, and appliances as well as to operate parts of the building itself, such as the elevators, water supply, and heating system. Given these combined uses, buildings account for a large portion of the world's energy consumption. In Brazil, approximately 54% of electric energy consumption comes from the residential, commercial, public, and service sectors [1]. In addition, although buildings are built to be used for many decades, after their initial construction, improvements are more difficult to deploy. Therefore, in light of climate change scenarios, it is very important to rethink the planning of buildings, including architectural attributes, life cycles, and construction processes.

At the international level, initiatives have been developed to promote energy efficiency, including environmental labeling and certification programs. In Brazil, the lack of investments in electric power generation and transmission, aggravated by the low water level in the reservoirs of the

country's hydroelectric plants, were the main causes that induced the 2001 energy crisis in the country, reducing the reliability and quality of electricity services, with actions to ration consumption and increase tariffs [2]. Therefore, the main Brazilian initiatives, such as the National Energy Conservation Policy [3] and the National Program for Energy Efficiency in Buildings—Procel Edifica, instituted by Eletrobrás/Procel in 2003—were boosted by the 2001 energy crisis.

Thus, under the leadership of the Brazilian Labeling Program for Buildings (Programa Brasileiro de Etiquetagem de edificações—PBE Edifica), which is a project of Procel and the National Institute of Metrology, Quality, and Technology (Instituto Nacional de Metrologia, Qualidade e Tecnologia—Inmetro), technical regulations regarding the energy efficiency of commercial, service, and public buildings (RTQ-C approved in 2009) and of residential buildings (RTQ-R approved in 2010) were developed to classify buildings based on their energy efficiency. Under this program, some buildings can earn the National Energy Conservation Label (Etiqueta Nacional de Conservação de Energia—ENCE).

According to Matos [4], the labeling of buildings and equipment has been responsible for much of the energy conservation achieved in several countries around the world. However, in Brazil, despite good results with the labeling of equipment, the labeling of buildings remains rather ineffective at modifying the processes and construction practices that are already consolidated in the market [4]. This ineffectiveness is likely due to both the brief existence of labeling and its usually voluntary nature. For Melo et al. [5], the methodology of technical regulations stimulates the application of bioclimatic strategies in building projects; in these projects, the environmental conditions of the region are considered, and the use of artificial air conditioning may even be reduced. Additionally, Krüger and Mori [6] reported that having a property with a high energy-efficiency ranking is valued enough that the sale or rent value may increase.

Considering the increase in residential development and its role in Brazil's energy consumption, initiatives and research aimed at energy efficiency in the building sector should be boosted. Regarding researches that analyze thermal and energy performance on a large scale, the use of representative buildings was verified, indicating guidelines that guide the construction of new buildings, as well as the revitalization of existing ones, aiming at energy efficiency. Triana et al. [7] suggest that a typology of the projects currently being built and an analysis of the thermal and energy performance of those projects could provide the basis for an efficient policy for the housing industry.

One of the modeling methods for predicting and analyzing aspects of overall building energy consumption performance is defined by the International Energy Agency (IEA) as bottom-up, based on physical building data [8]. This method considers a sample of representative dwellings. The dwellings are then characterized based on physically measurable variables such as the areas of their different elements (e.g., floor, roofing, or walls), thermal characteristics, and ventilation rate. The combination of physical construction data with empirical research data on housing and building operations provides a means to estimate energy consumption and to develop different scenarios; this approach is already used in the planning of energy efficiency programs throughout the world [9], including Canada [10] and Finland [11].

In Brazil, Tavares [12] conceived five models of Brazilian residential buildings and applied an energy life cycle analysis methodology to each one. Matos [4] investigated the energy performance of the envelopment of vertical residential buildings in Natal, RN, using the RTQ-R prescriptive method for representative buildings; the buildings were chosen based on typological and constructive characteristics. Meira [13] comparatively analyzed the energy efficiency of residential buildings in the Pilot Plan of Brasília, DF, applying RTQ-R. For this analysis, three quantitatively representative typologies were selected. Triana et al. [7] defined representative models for the My Home My Life Program (Programa Minha Casa Minha Vida) projects and evaluated their thermal and energy performance in relation to Energy Labeling. Schaefer and Ghisi [14] developed a method to define reference buildings for social housing in southern Brazil, analyzing the geometry of the buildings.

Lamberts et al. [15] and Carlo and Lamberts [16] explain that the RTQ-C prescriptive method equations for calculating the envelope efficiency of these buildings were developed from the performance analysis of five prototypes. These representative models have typologies that were elaborated as a result of a photographic survey of 1103 commercial and institutional buildings in five Brazilian capitals (Salvador, Recife, Florianópolis, São Paulo, and Belo Horizonte). The external characteristics of the buildings were considered as shape, number of floors, dimensions, percentage of openings, sun protection (existence, angle, and dimension), and glass colors.

Therefore, considering the need for research regarding the application of energy-efficiency guidelines, instruments, and activities for buildings in Brazilian cities and the identified knowledge gap regarding the energy efficiency of buildings in Vitória, ES, the objectives of this article were defined. These objectives are to define typologies that represent the multi-family residential buildings of a neighborhood in the capital of Espírito Santo in southeastern Brazil and to evaluate the thermal and energy performance of these typologies in relation to the Building Labeling of RTQ-R. The housing units (HUs) were analyzed for cooling degree-hours (cooling for summer), relative consumption for refrigeration (artificial cooling), and envelope performance for summer, with a final classification of the HUs by the water heating system; finally, a conclusion was drawn regarding the energy efficiency results of the entire multifamily building. These results contribute to an efficiency policy for the housing industry and allow examination of the incorporation of measures that promote energy efficiency within the sector.

2. Materials and Methods

The authors mentioned in the introduction define the reference construction as a model that represents the reality of what will be studied and defend its use for large-scale performance studies, indicating guidelines that guide the construction of new buildings, as well as upgrading existing ones for better thermal and energy performance. Their procedures for defining representative buildings are similar:

- 1 Definition of the object of study;
- 2 Definition of the building according to its function, bioclimatic region, among others;
- 3 Identification of variables related to the building performance (physical characteristics, geometry, envelope composition, etc.);
- 4 Analysis of the most recurrent data;
- 5 Definition of the representative building.

So, to define the typologies that represent multi-family residential buildings and to evaluate their HUs thermal and energy performance, the following steps were performed:

- Definition of existing residential typologies in the neighborhood selection, survey, and mapping of existing buildings, followed by classification into the defined typologies, and selection of the representative buildings of Jardim Camburi (Section 2.1);
- Characterization of the representative buildings (Section 2.2);
- Calculation (Section 3) of the current efficiency level of the representative buildings through the prescriptive method of RTQ-R (Section 2.3).

2.1. Definition of Typologies and the Survey of Buildings

Jardim Camburi is the neighborhood analyzed, in the capital of Espírito Santo (Vitória), southeastern Brazil. This region of study was defined because it has vertical residential buildings, which were built mainly from the 1980s, being one of the most recent neighborhoods of the capital. The limits of the neighborhood (Figure 1), which is 2.61 km² in area, were consulted in the Portal of the Vitória City Hall [17,18].

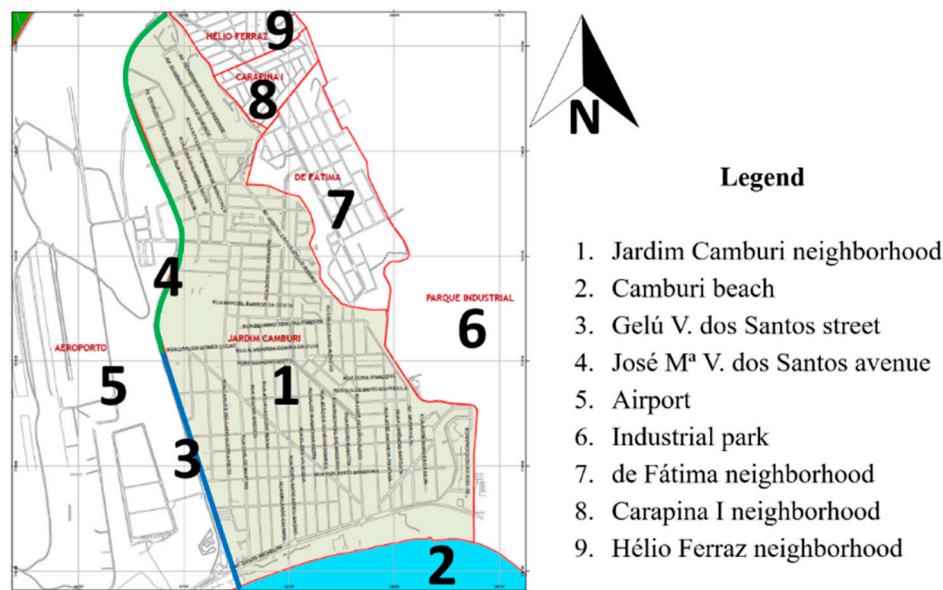


Figure 1. Detailed map of Jardim Camburi, Vitória Espírito Santo (ES), and the boundaries of the neighborhood.

The capital of Espírito Santo is located in the southeast region of Brazil, in the bioclimatic zone 8, according to NBR 12220-3 [19], and has flat areas near the shore. It is located at LAT 20° 16' S and LONG 40° 17' W, with mean temperatures between 20 °C and 28.4 °C and a mean relative humidity of 84% [20]. According to the Prefeitura Municipal de Vitória [17], 39,157 people lived in the Jardim Camburi neighborhood in 2010. Since the 1980s, the urbanization and densification of the neighborhood have become more intense, and it is now typically residential, although the service trade sector is also present [21].

At first, a face-to-face route was taken in the main and some secondary roads of the neighborhood to recognize the existing volumes within the scope of multifamily residential buildings. Then, physical and geometrical elements were observed to draw a classification profile in typologies, in order to determine the representative residential buildings of the neighborhood. The number of floors, the predominant color, the existence of balconies and the existence of other shading elements were considered. The analysis was visual and external to the buildings.

As identified in the survey, the existence of several single-family residential buildings with up to three floors and only three-storey multi-family buildings in the Residencial Praia de Camburi condominium, it was determined to study the multi-family residential buildings with four or more floors, thus contributing to the grouping into existing typologies of multifamily buildings with apartments. In addition, it was decided that the residential Atlantica Ville would not be part of the research, given the lack of standardization of real estate.

The result of this first contact was the observation that buildings with four and five floors have similar characteristics regarding the shape and distribution of the floors, being grouped in typology 1 when there is no balcony, and in typology 2, when there is a balcony. Buildings on the edge of the neighborhood with Gelú Vervloet dos Santos street and Jose Maria Vivacqua dos Santos avenue are taller, with similar shape and distribution of floors and with balconies. In this way, they were grouped in typology 3. The other multi-family residential buildings, also similar in the shape and distribution of floors, were grouped in typology 4, without the balcony, and typology 5, with the balcony.

Thus, for the purposes of the survey and the subsequent definition of representative building typologies, multi-family residential buildings were grouped into the following categories:

- Typology 1: Residential buildings with four or five floors without balconies;
- Typology 2: Residential buildings with four or five floors with balconies;

- Typology 3: Residential buildings with 15 to 22 floors;
- Typology 4: Residential buildings with six to 12 floors without balconies; and
- Typology 5: Residential buildings with six to 12 floors with balconies.

The survey in the Jardim Camburi neighborhood was completed through a face-to-face analysis and with the help of the free Google Earth 7 tool, in which all the streets were traversed and all existing buildings have been checked. A spreadsheet was prepared for the collection of data from the external typological elements of buildings based on the bibliographic research and visual analysis of buildings. The analysis was visual and external to the buildings; no half-basement floors were counted for either common or standard use. Mixed-use buildings (commercial ground floor with higher residential floors) were included in the research. Buildings under construction at the time of the survey were not included. Based on these parameters, in January 2017, 663 multi-family residential buildings with four or more floors built in Jardim Camburi were identified in the survey (Figure 2). The most frequent typologies are 1, 2, and 5.

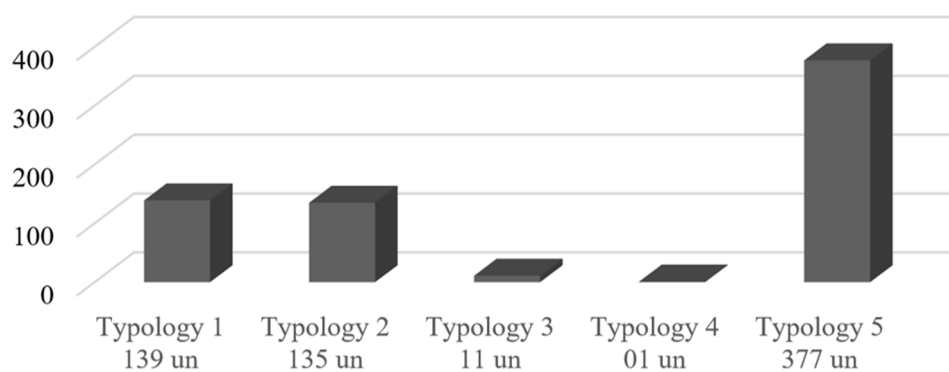


Figure 2. Histogram of the building typologies identified in the survey.

In Figure 3, an image elaborated from Google Earth, presents the location of the buildings according to the typologies surveyed in the neighborhood. Some buildings have shading elements other than the balconies, and in buildings with four or five floors, some HUs have post occupancy installed canvas awnings, showing that their users felt the need for sun protection. Most of the buildings are light-colored and have balconies with glass balustrades.

The buildings with four or five floors are mainly in the occupancy nucleus of the neighborhood (Figure 3) and generally have similar floor distribution, with a ground floor on stilts and higher floors with apartments. Buildings of six to 12 floors with balconies were located throughout and were predominant in the neighborhood, totaling 377 buildings. Within typology 5, two types of well-defined buildings were observed in the survey: Buildings with 10 floors that generally have the ground floor on stilts and have small balconies (usually serving only the living room), and buildings with 10 floors where the ground floor generally includes covered common areas and large balconies serve more than one extended-use space (EUS). No buildings with 13 or 14 floors were identified in the neighborhood.

Buildings from 15 to 22 floors are located in the Gelú Vervloet dos Santos area, where zoning is different from the other areas of the neighborhood. Roofing with the fascia board and fiber cement without painting are both prevalent. A few buildings with four floors have noncontinuous openings for ventilation in the roof fascia board. Leisure areas (barbecue and pool) exist on top of some buildings with six or more floors. Buildings with solar panels on their roofs are rare.

Based on the results presented in Figure 2, as well as the visual analysis and physical observations, it was found that typologies 3 and 4 are poorly representative, totaling 12 of the 663 buildings and typology 5 shows a greater representation, with 337 buildings. Two types of well-defined buildings were observed during the classification. Thus, based on the results and access opportunity for data

collection, three typologies (1, 2 and 5) were selected and four representative buildings were defined (Figure 4):

- Building A represents typology 1: Four floors and no balconies.
- Building B represents typology 2: Four floors, with balconies.
- Building C represents the typology 5: Ten floors, with small balconies.
- Building D represents the typology 5: Ten floors, with large balconies.

In Figure 3, the white arrows indicate the location of the representative buildings: Upper left: Building A; upper right: B; lower left: C; and lower right: D.



Figure 3. Location of the buildings according to the typologies surveyed in the neighborhood.

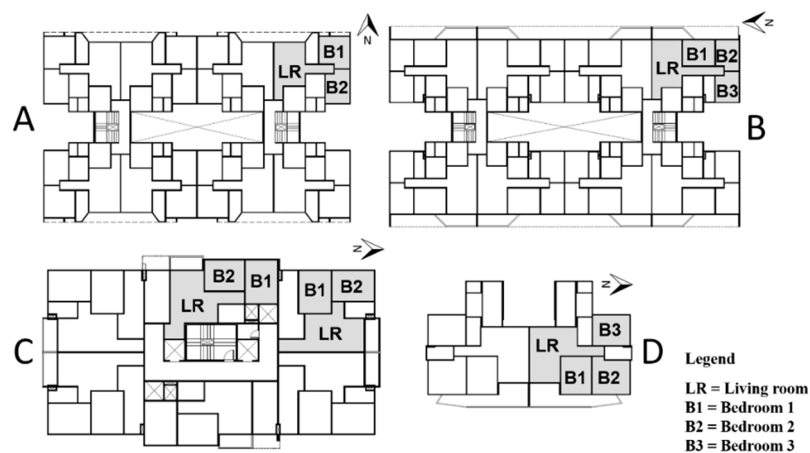


Figure 4. Schematic floor plan of each representative building.

2.2. Characterization of the Representative Buildings

For the characterization of the four representative buildings (Tables 1 and 2), data were collected based on the prescriptive method of the RTQ-R [22], notes taken during the survey, architectural designs approved in the PMV, construction photos, technical visits, and interviews with residents and responsible engineers when necessary and timely.

Table 1. Data collected for the representative buildings.

Collected Data	Building A	Building B	Building C	Building D
Year of project approval by the PMV	1981	1981	1996	2012
Individual energy measurement	Yes	Yes	Yes	Yes
Individual water measurement	No	No	No	Yes
Area of the HU	58.80 m ²	75.23 m ²	Standard 1 = 54.66 m ² and Standard 2 = 55.15 m ²	93.00 m ²
HU living area (without walls and balconies)	52.86 m ²	63.67 m ²	Standard 1 (COL 1,2,4,5) = 46.66 m ² and Standard 2 (COL 3, 6) = 45.16 m ²	72.46 m ²
Floors	4 (1 stilts + 3 standard)	4 (1 stilts + 3 standard)	10 (1 stilts + 9 standard).	10 (ground floor + 9 standard). It has a half basement.
HUs per Floor	08	08	06	02
Ceiling height (floor to ceiling)	2.71 m	2.71 m	2.80 m	2.70 m
Rooms per HU	02	03	02	03
Bathrooms per HU	02	02	01	03
Bathrooms with natural ventilation per HU	01	01	01	02
Cross ventilation in HU	Yes	Yes	Standard 1 = yes and Standard 2 = no	Yes
Water Heating	Electric.	Electric.	Electric.	Electric.
Drinking water conservation elements	Sanitary bowl with box attached	Sanitary bowl with box attached	Sanitary bowl with box attached Faucet aerators in bathrooms and kitchen.	Sanitary bowl with box attached and dual flush; Faucet aerators in bathrooms and kitchen.
Thermal transmittance (U) of the external walls	2.39 W/(m ² K). 9 cm ceramic block and mortar.	2.39 W/(m ² K). 9 cm ceramic block and mortar.	2.24 W/(m ² K). 12 cm ceramic block and mortar	2.39 W/(m ² K). 9 cm ceramic block and mortar
Absorbance (α) of external walls	Values depending on the space: 0.7; 0.37; 0.55; or 0.27.	Values depending on the space: 0.7; 0.37; 0.55; or 0.27.	Values depending on the space: 0.41; 0.42; or 0.34.	0.45
Thermal transmittance (U) of roofing	2.06 W/(m ² K). 10 cm solid slab and fiber cement roof.	2.06 W/(m ² K). 10 cm solid slab and fiber cement roof.	2.06 W/(m ² K). 10 cm solid slab and fiber cement roof.	2.06 W/(m ² K) was adopted. 18 cm tensioned flat slab and fiber cement roof.
Absorbance of roofing	0.65	0.65	0.65	0.65

Note: COL = Column number within the building.

Table 2. Areas of spaces and walls of representative buildings.

	Description	Living Room	Bedroom 01	Bedroom 02	Bedroom 03
Representative Building A	Living area without hallways	14.40 m ²	9.60 m ²	8.40 m ²	-
	Living area with hallways	18.40 m ²	9.60 m ²	8.40 m ²	-
	Area of external openings	4.20 m ²	1.40 m ²	1.40 m ²	-
	Area of internal walls COL 1, 4, 6, 7	48.15 m ²	24.95 m ²	24.55 m ²	-
	Area of external walls COL 1, 4, 6, 7	4.47 m ²	7.14 m ²	5.38 m ²	-
	Area of internal walls COL 2, 3, 5, 8	48.15 m ²	16.01 m ²	14.93 m ²	-
	Area of external walls COL 2, 3, 5, 8	4.47 m ²	7.14 + 8.94 m ²	5.38 + 9.62 m ²	-
Representative Building B	Living area without hallways	16.32 m ²	10.00 m ²	8.03 m ²	7.53 m ²
	Living area with hallways	21.59 m ²	10.00 m ²	8.03 m ²	7.53 m ²
	Area of external openings	4.80 m ²	1.40 m ²	1.40 m ²	1.40 m ²
	Area of internal walls COL 1, 4, 6, 7	58.99 m ²	23.60 m ²	14.52 m ²	13.98 m ²
	Area of external walls COL 1, 4, 6, 7	3.87 m ²	7.95 m ²	5.37 + 9.21 m ²	8.67 + 5.37 m ²
	Area of internal walls COL 2, 3, 5, 8	58.99 m ²	23.60 m ²	23.73 m ²	22.65 m ²
	Area of external walls COL 2, 3, 5, 8	3.87 m ²	7.95 m ²	5.37 m ²	5.37 m ²
Representative Building C	Living area without hallways COL 1, 2, 4, 5	16.21 m ²	9.00 m ²	8.33 m ²	16.21 m ²
	Living area with hallways COL 1, 2, 4, 5	17.16 m ²	9.00 m ²	8.33 m ²	17.16 m ²
	Living area without hallways COL 3, 6	14.28 m ²	9.23 m ²	8.00 m ²	14.28 m ²
	Living area with hallways COL 3, 6	16.37 m ²	9.23 m ²	8.00 m ²	16.37 m ²
	Area of external openings	3.30 m ²	1.56 m ²	1.44 m ²	-
	Area of internal walls COL 1, 2, 4, 5	43.68 m ²	25.13 m ²	14.91 m ²	43.68 m ²
	Area of external walls COL 1, 2, 4, 5	3.98 m ²	5.72 m ²	5.42 + 9.52 m ²	3.98 m ²
	Area of internal walls COL 3, 6	36.68 m ²	23.45 m ²	19.25 m ²	36.68 m ²
	Area of external walls COL 3, 6	3.98 m ²	5.72 + 2.24 m ²	2.24 + 7.52 m ²	3.98 m ²
Representative Building D	Living area without hallways	19.54 m ²	10.10 m ²	11.74 m ²	9.90 m ²
	Living area with hallways	21.83 m ²	10.10 m ²	11.74 m ²	9.90 m ²
	Area of external openings	5.50 m ²	1.65 m ²	3.52 m ²	1.65 m ²
	Area of internal walls	45.24 m ²	22.70 m ²	17.39 m ²	15.68 m ²
	Area of external walls	7.43 m ²	2.70 + 7.70 m ²	8.64 + 9.59 m ²	7.70 + 9.45 m ²

Note: COL = Column number within the building.

The data collected for the characterization were mainly the building's bioclimatic zone, geographic north, areas of the spaces and of the internal and external walls, ceiling heights, number of rooms and floors, compositions and colors of external walls and roofs, openings (quantity, areas, and form

of operation), dimensions and types of shading elements, water heating system, drinking water conservation elements, and water and energy measurements.

The external colors were defined visually, and the closest corresponding color and its absorbance value (α) were adopted with reference to item B of the general Annex V of the RTQ-R and NRB 15220-2 [23]. When a space had more than one color on its outer walls, the weighted value of absorbance was calculated. The compositions of the external walls and roofing materials of the buildings were determined by a technical visit and/or interview with a resident, and the value for thermal transmittance (U) was selected based on item B of the general Annex V of the RTQ-R. For building D, specifications similar to those in the RTQ-R (Table 1) were adopted. In addition to the use of the RTQ-R and its manual, any doubts about calculations were clarified by using the forum available on the portal of Portal PBE Edifica [24].

2.3. Prescriptive Method of RTQ-R

The Quality Technical Regulation for the Energy Efficiency Level of Residential Buildings (RTQ-R) was published in September 2010 and is governed by Inmetro Ordinance number 18 of 16 January 2012 [22]. RTQ-R contains, as complementary documents, the Conformity Assessment Requirements for the Energy Efficiency of Buildings (Requisitos de Avaliação da Conformidade para Eficiência Energética de Edificações—RAC) [25] and the manual for their application [26]. Membership is voluntary. The RTQ-R specifies technical methods and requirements for the classification of residential buildings according to the energy efficiency, allowing the labeling of single-family and multi-family buildings (weighted result of the evaluation of all autonomous HUs of the building), and common areas.

For the HUs, the requirements regarding the thermal performance of the envelope, the water heating system, and possible subsidies (e.g., porosity of natural ventilation, rational water use, and ceiling reflectance) are evaluated in the RTQ-R. For common areas, factors including artificial lighting systems, elevators, centrifugal pumps, equipment, and water heating systems for baths, swimming pools, and saunas are considered in the RTQ-R. Romero and Bruna [27] affirm that the use of solar thermal panels for heating water in the residential sector should be considered a significant sustainability practice.

The RTQ-R evaluation method can be a prescriptive or performed by computer simulation. Based on the score obtained, the rating varies from A (more efficient) to E (less efficient), as shown in Table 3. This classification, together with other energy performance data, is documented in the ENCE provided to the evaluated property. The prescriptive method is applicable to most typologies constructed in the country and stimulates the application of architectural strategies appropriate to the bioclimatic zone (BZ); however, some practices can be evaluated only by simulation [28,29], in addition to evaluating the skill of the professionals involved and the many data required [30,31]. Therefore, Giacomini and Calmon [32] emphasize the importance of professional practice being in harmony with the academy and affirm that the application of the RTQ-R not only allows the consumer to compare available properties but also favors the design of quality architectural projects, thus contributing to energy conservation.

Table 3. Efficiency level classification by score [32].

Score	Efficiency Level	Corresponding Color in ENCE
Score ≥ 4.5	A	Green
$3.5 \leq \text{Score} < 4.5$	B	Light green
$2.5 \leq \text{Score} < 3.5$	C	Yellow
$1.5 \leq \text{Score} < 2.5$	D	Orange
Score < 1.5	E	Red

The RTQ-R [22] prescriptive method classifies the energy efficiency level of the HUs using an equation that gives the HU a total score for its efficiency level (Score_{HU}); the score involves the

numerical equivalent of the envelope (EqNumEnv; thermal performance when the HU is naturally ventilated; the coefficient (a) corresponds to the BZ of the building, the numerical equivalent of the water heating system (EqNumAA), and the total points obtained with bonuses (Equation (1)). For BZ 8, the value of a is 0.65.

$$\text{ScoreHU} = (a \times \text{EqNumEnv}) + [(1 - a) \times \text{EqNumAA}] + \text{Bonuses} \quad (1)$$

Requirements related to the thermal transmittance, thermal capacity, solar absorbance, ventilation, and natural light must be respected, or the maximum rating will be ‘C’. In the calculations developed in this study, an editable worksheet was used that was developed by the Laboratory of Energy Efficiency in Buildings (Laboratório de Eficiência Energética em Edificações—LabEEE); the worksheet is available on the Catálogos [33].

The thermal performance of the envelope is obtained by the numerical equivalent of the naturally ventilated envelope (EqNumEnv). Each BZ has a corresponding equation, and the EqNumEnv for cooling (EqNumEnvResfr) and for heating (EqNumEnvA) are considered. However, the latter is not necessary for BZs 5 through 8. Since the neighborhood of Jardim Camburi is in BZ 8, the EqNumEnv for heating was not calculated, and thus the EqNumEnv is equal to the EqNumEnvResfr, which corresponds to the summer envelope in this case. Therefore, the degree-hours indicator (GHR), which represents the annual sum of degree-hours and uses the temperature of 26 °C as the base for cooling, must be calculated for each EUS.

The numerical equivalent when the HU is air conditioned (EqNumEnvRefrig) must also be calculated, although only for informational purposes and only for the bedrooms. The water heating system for the showers in the four representative buildings is electric and is classified as level 1 (classification E) since the minimum power installed for this equipment is assumed to be 4600 W.

According to Lamberts et al. [15], the equations for the prescriptive method of calculating the envelope efficiency of public, commercial, and service buildings were developed by using performance analyses of five prototypes based on representative typologies of existing buildings in five Brazilian capitals. Triana et al. [7] worked on the characterization and mapping of the typologies of Brazilian social housing projects, which resulted in the definition of representative models in which thermal and energy performances were evaluated according to Procel Edifica. This is the perspective that shaped the methodology of this research.

3. Results and Discussion

The results presented refer to the actual performance of each representative building and its HUs in the cooling degree-hours (cooling for summer), relative consumption for refrigeration (artificial cooling), envelope performance for summer, and classification of the water heating system (Table 4). Graphical representations based on calculations of the current efficiency of the HUs of each building are presented to support the discussion (Tables 5–8).

Table 4. Comparison of the conformity of representative buildings with the quality technical regulation for the energy efficiency level of residential buildings (RTQ-R) requirements for bioclimatic zone (BZ) 8.

Representative Building	Wall	Roofing	% Natural Light in All EUSs	% Natural Ventilation in All EUSs
	If $\alpha \leq 0.6$ Then $U \leq 3.70$ If $\alpha > 0.6$ Then $U \leq 2.50$	If $\alpha \leq 0.4$ Then $U \leq 2.30$ If $\alpha > 0.4$ Then $U \leq 1.50$		
A	Yes	No	No	No
B	Yes	No	No	No
C	Yes	No	Yes	No
D	Yes	No	Yes	No

Note: α (absorbance); U (thermal transmittance); EUS (extended-use space).

Table 5. Graphical representation of the standard floor of Representative Building A with the classification based on energy efficiency assessment.


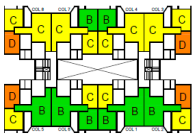
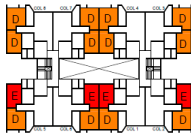
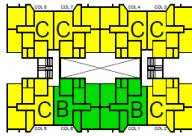
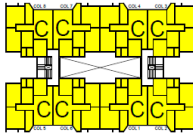
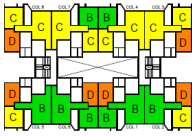
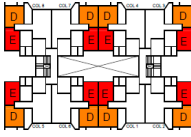
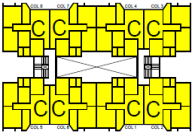
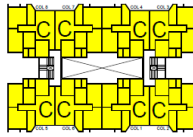
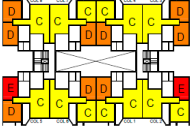
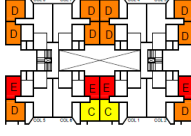
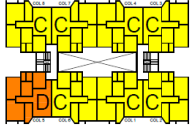
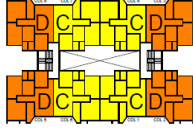
Current Situation—Building A					A B C D E
HU 	Cooling Degree-Hours (Cooling for Summer in Each EUS)	Relative Refrigeration for Consumption in Each Room (If Artificial Cooling is Used)	Envelope Performance for Summer	Final Classification of HU with Water Heating System	
Standard first floor					
Standard intermediate floor (x1)					
Standard top floor					

Table 6. Graphical representation of the standard floor of Representative Building B with the classification based on energy efficiency assessment.


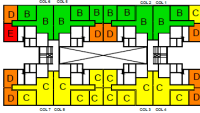
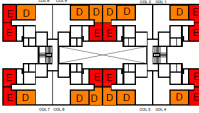
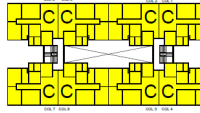
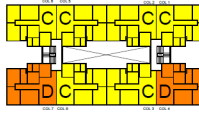
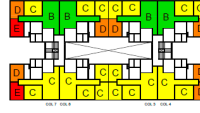
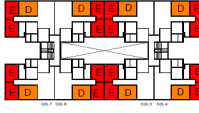
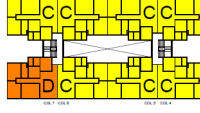
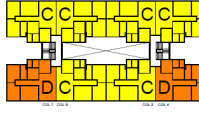
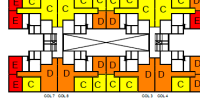



Current Situation—Building B					A B C D E
HU 	Cooling Degree-Hours (Cooling for Summer in Each EUS)	Relative Refrigeration for Consumption in Each Room (If Artificial Cooling is Used)	Envelope Performance for Summer	Final Classification of HU with Water Heating System	
Standard first floor					
Standard intermediate floor (x1)					
Standard top floor					

Table 7. Graphical representation of the standard floor of Representative Building C with the classification based on energy efficiency evaluation.


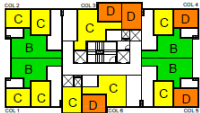
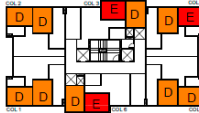
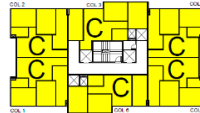

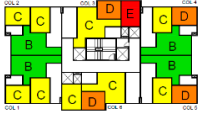



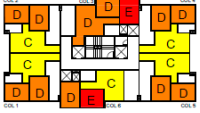




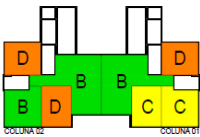
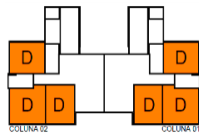
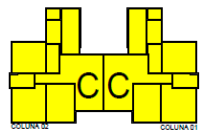
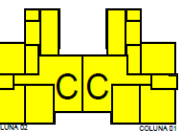
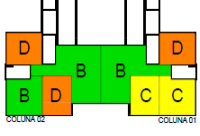
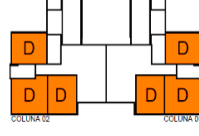
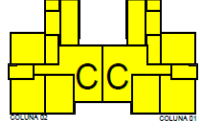
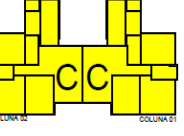
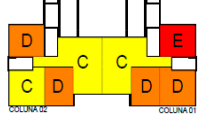
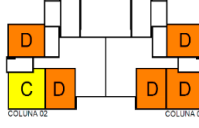
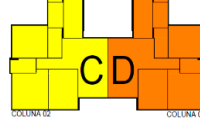
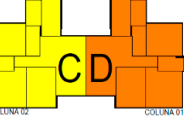
Current Situation—Building C					A B C D E
HU 	Cooling Degree-Hours (Cooling for Summer in Each EUS)	Relative Refrigeration for Consumption in Each Room (if Artificial Cooling is Used)	Envelope Performance for Summer	Final Classification of HU with Water Heating System	
Standard first floor					
Standard intermediate floor (x7)					
Standard top floor					

Table 8. Graphical representation of the standard floor of Representative Building D with the classification based on energy efficiency evaluation.

Current Situation—Building D					A B C D E
HU 	Cooling Degree-Hours (Cooling for Summer in Each EUS)	Relative Refrigeration for Consumption in Each Room (if Artificial Cooling is Used)	Envelope Performance for Summer	Final Classification of HU with Water Heating System	
Standard first floor					
Standard intermediate floor (x7)					
Standard top floor					

Building A represents the 139 buildings classified in typology 1, i.e., 21% of the 663 multi-family residential buildings in Jardim Camburi. Building A was approved by the PMV in 1981 and has four floors: A ground floor on stilts and three floors with standard apartments (similar floor plans). Each standard floor has eight apartments: Four facing north and four facing south. No shading elements such as balconies or brise-soleils are present, although the shape of the building provides shading at certain times of day. The largest bedroom in each HU does not meet the minimum illumination requirement (12.5%), and neither bedroom meets the minimum ventilation requirement for BZ 8 (10%);

however, the living room meets both minimum requirements (Figures 5 and 6, and Table 4). In all the apartments, cross ventilation is present, and one of two bathrooms has natural lighting and ventilation.

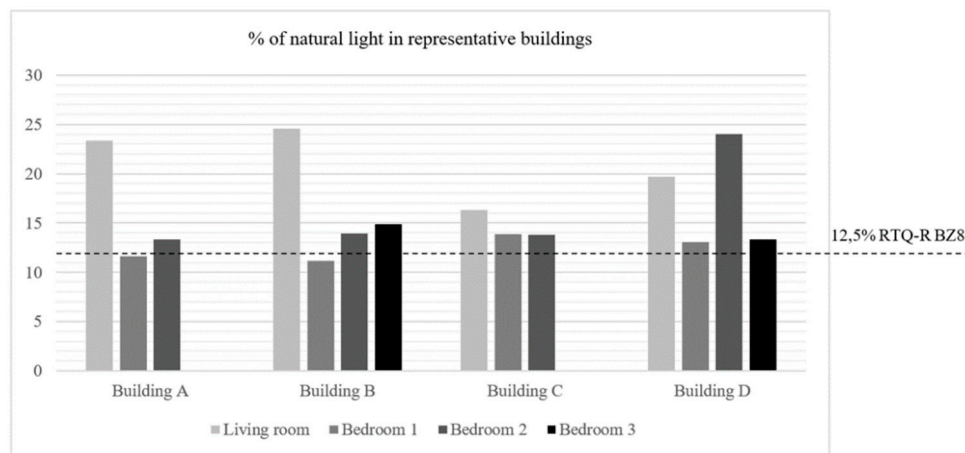


Figure 5. Percentage of natural light in the extended-use spaces (EUSs) of the representative buildings.

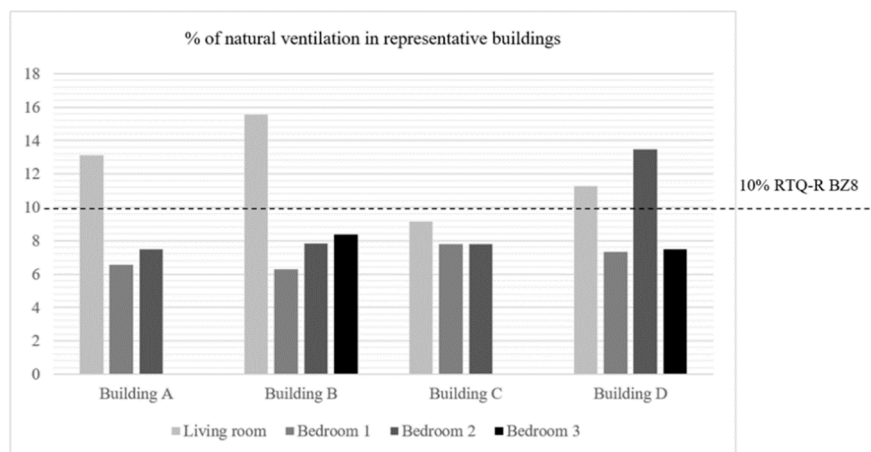


Figure 6. Percentage of natural ventilation in the EUSs of the representative buildings.

According to residents who have renovated their properties, the walls are composed of ceramic blocks, and the slab is composed of concrete, approximately 10 cm in thickness. The roofing of the building is composed of fiber cement without special paint or a thermal blanket. The outer walls are painted with colors visually similar to dark green, with an absorbance of 0.7, and ivory (color 12), with an absorbance of 0.34. The walls comply with the RTQ-R transmittance and thermal absorbance requirements; however, the roofing does not (Table 4). The apartments have individualized energy measurements, but the building has only a single, combined measurement for drinking water consumption. Only the toilets with attached boxes can be considered water conservation equipment in the HUs.

When analyzing the degree-hours indicator for cooling (cooling for summer) for the three floors using Table 5, the thermal performance of the envelope of the naturally ventilated building is better in the apartments on stilts and facing south and worse in the apartments on the top floor and in the smaller bedrooms with two external walls, one of which faces north; these bedrooms receive solar incidence for most of the day. The shading due to the shape of the building also favors a good performance of the interior spaces. Thus, of the 24 apartments, 21 received classification C for the envelope performance for summer, two received classification B, and one received classification D. Regarding the relative refrigeration (artificial cooling) consumption, the smaller bedrooms, particularly those on the intermediate floor, have the worst performance. The best performance is in the two larger,

south-facing bedrooms with few exterior walls and on the top floor. The type of water heating system in the building influenced the final classification of the HU, resulting in 20 HUs with a classification of C and four with a classification of D. Thus, the classification of the multi-family building as a whole is C.

Building B represents the 135 buildings classified in typology 2, i.e., 20% of the 663 buildings surveyed. Similar to the representative Building A, Building B was approved in 1981 and has four floors: A ground floor on stilts and three floors with standard apartments (similar floor plans), with eight apartments per floor: Four facing east and four facing west (Table 6). Living room balconies and the shape of the building serve as shading elements. The largest bedroom does not meet the minimum lighting percentage (12.5%), but the other two do. None of the bedrooms meet the minimum ventilation percentage for BZ 8 (10%), but the living room meets both lighting and ventilation requirements. Cross ventilation is present in all the apartments, and one out of the two bathrooms has natural lighting and ventilation.

Buildings B has the same specifications for the process of constructing the envelope and roof, as well as the same external color as Building A; consequently, it has the same values for thermal transmittance and absorbance. The apartments have individualized energy measurements, but the building has only a single, combined measurement for the drinking water consumption. Only the toilets with attached boxes but without a dual flush can be considered as water conservation equipment.

As shown in Table 6, the thermal performance of the envelope of the naturally ventilated building is better in the apartments on stilts and facing east. The balconies and building shape helped to raise the ranking of some EUSs, both for cooling for summer and for artificial cooling. The worst performance occurred in the apartments on the top floor and in the smaller bedrooms with two external walls, especially when the walls are facing west and north. Thus, of the 24 apartments, 18 received classification C for the envelope performance for summer, and six received classification D. The smaller bedrooms, particularly on the intermediate floor, have the worst refrigeration (artificial cooling) consumption performance. The top floor has a better performance; in this case, regardless of the solar orientation, the spaces with the same internal areas and openings received the same classification. Therefore, 14 HUs have a final classification of C, and 10 have classification D. The classification of the entire multi-family building was C.

Buildings C and D represent the 377 buildings classified in typology 5, i.e., 57% of the 663 buildings surveyed. In this typology, during the survey phase, variations were noted in the balconies. Thus, the two buildings (C and D) were selected to represent typology 5.

The representative Building C, approved in 1996, has 10 floors: A ground floor on stilts and nine floors with standard apartments (two types of floor plans). There are six apartments in each standard arrangement, two facing north, two facing south, one facing east, and one facing west (Table 7). Only the balconies can be considered shading elements, and they serve only the living room. All EUSs meet the minimum lighting requirement (12.5%). However, only the living room of the apartments in columns 3 and 6 meet the minimum ventilation percentage for BZ 8 (10%), as shown in Figures 5 and 6, and Table 4. Only the apartments in columns 1, 2, 4, and 5 have a cross ventilation, and the bathroom has both a ventilation and natural light.

According to the condominium manager and the engineer who performs the calculations for the structures, the walls are composed of ceramic blocks, and the slab is composed of concrete, approximately 10 cm in thickness. The roof of the building is composed of fiber cement without a special paint or thermal blanket. The exterior walls are painted with colors that are visually similar to color 10, with an absorbance of 0.5, color 12, with an absorbance of 0.34, and color 16, with an absorbance of 0.78. The walls comply with the RTQ-R thermal transmittance and absorbance requirements; however, the roofing does not (Table 4). The apartments have individualized energy measurements, but the building has only a single, combined measurement for drinking water consumption. Toilets with attached boxes, but without a dual flush, and faucet aerators in the kitchens and bathrooms can be considered water conservation equipment in the HUs.

Analyzing the data in Table 7, the thermal performance of the envelope of the naturally ventilated building is better in the apartments facing south. The five columns of apartments obtained the same classifications whether they were on stilts or on the intermediate floors; only one bedroom in the west-facing apartments has a better classification, and only when built on stilts. The balconies contributed to the better thermal performance of the living rooms, especially in the north-facing spaces; however, for the east-facing living room, the score for shading could not be considered. In RTQ-R, depending on the building facade orientation and the latitude of the terrain, certain angles are not recommended for scoring in the prescriptive method (due to variable shading). The worst performance was in the apartments on the top floor and in the bedrooms with two outer walls that receive sunshine most of the day (northeast or northwest). Thus, of the 54 apartments, 41 received classification C for the envelope performance for summer and 13 received classification D.

Regarding the relative energy consumption for refrigeration (artificial cooling), the intermediate floors presented the worst performance, with the highest number of EUSs with a classification of E. Considering the envelope performance for summer and the final classification of the apartments including the water heating system, only the first-floor, west-facing apartment presented different results. Therefore, 40 HUs had a final classification of C, and 14 had a final classification of D. The classification of the entire multi-family building was C.

The representative Building D, approved in 2012, has 10 floors: A ground floor, with a garage on stilts and isolated common areas, and nine floors with standard apartments, in addition to a garage in the half basement. The right column does not have an apartment on stilts, and in the left column, the three bedrooms are on stilts. On each standard floor, there are two apartments, and both of them face east (Table 8). The balconies shade two of the three bedrooms and the living room. All EUSs meet the minimum lighting requirement (12.5%). However, only the living room and one of the three bedrooms meet the minimum ventilation requirement for BZ 8 (10%), as shown in Figures 5 and 6, and Table 4. The apartments have cross ventilation, and two of the three bathrooms have a natural ventilation.

According to visits to the building while under construction, the walls are composed of ceramic blocks, and the tensioned flat slab is approximately 18 cm in thickness. For this analysis, the same composition as representative buildings A, B, and C was adopted, which is the most similar to the composition of the existing roofs in Annex V of the RTQ-R. The roof of the building is composed of fiber cement without a special paint or thermal blanket. The outer walls are all the same color, which is visually similar to the color 03, with an absorbance of 0.45. The walls comply with the RTQ-R thermal transmittance and absorbance requirements; however, the roofing does not comply. The apartments have individualized water and energy measurements. Toilets with attached boxes and a dual flush, showers with flow restrictors, and faucet aerators in the kitchens and bathrooms can be considered water conservation equipment in the HUs.

Table 8 shows that the thermal performance of the naturally ventilated building envelope is better in the bedrooms with southeast-facing external walls and in the living rooms on the first and intermediate floors, all obtaining classification B. The balconies shade all the EUSs facing east, i.e., the living rooms and bedrooms 1 and 2. However, based on the shading angles scoring rule of the RTQ-R, it was not possible to classify room 1 (east façade and the window area is less than 25% of the floor area). The majority of the EUSs that were scorable had their classifications increased by one level due to shading.

The worst performance was in the apartments on the top floor, particularly in the bedrooms with northwest-facing exterior walls. Thus, of the 18 apartments, 17 received classification C for the envelope performance for summer, and one received classification D. Regarding the relative refrigeration (artificial cooling) consumption, only the top-floor bedroom with southeast-facing external walls in the left column received classification C, whereas the others received classification D. The envelope performance for summer and the final classification of the apartments, including

the water heating system, all presented the same results. Therefore, the classification of the entire multi-family housing building was C.

The results show that the water heating system influences the energy efficiency of the building and may even change the final classification. Meeting the requirements for ventilation and natural light also influenced the change in the classification of some extended-use spaces. Despite being approved by the PMV as meeting the ventilation and illumination requirements of the municipality, none of the buildings met the minimum ventilation percentage requirements for all EUSs, and two met the percentage natural light requirements. The presence of shading elements positively affects the building energy efficiency. The compliance criteria for the thermal properties of the roofs for BZ 8 were not met in any of the buildings, although the compositions of the walls met the requirements.

In terms of the cooling degree-hours (cooling for summer) and consequently the envelope performance for summer, the best performance was generally in the HUs on stilts, with shading elements, with light colors, or facing south or east. The worst performance occurred in the HUs on the top floor, with larger areas of external walls, or facing north or west. By contrast, for the relative refrigeration (artificial cooling) consumption, the best performance was on the top floor. However, few external walls and solar orientation to south and east also contribute to the good refrigeration (artificial cooling) performance.

Figures 7–9 show the final classification of the HU with the water heating system, so that the level of efficiency achieved can be visualized, considering the position of the floor in the analysis in the four representative buildings.

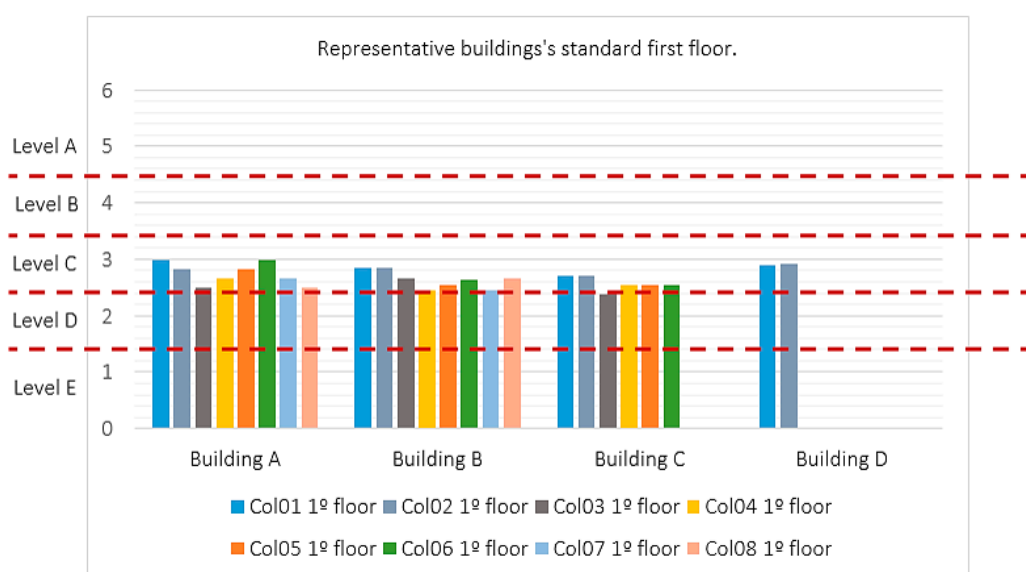


Figure 7. Final classification of the housing unit HU (standard first floor) with the water heating system.

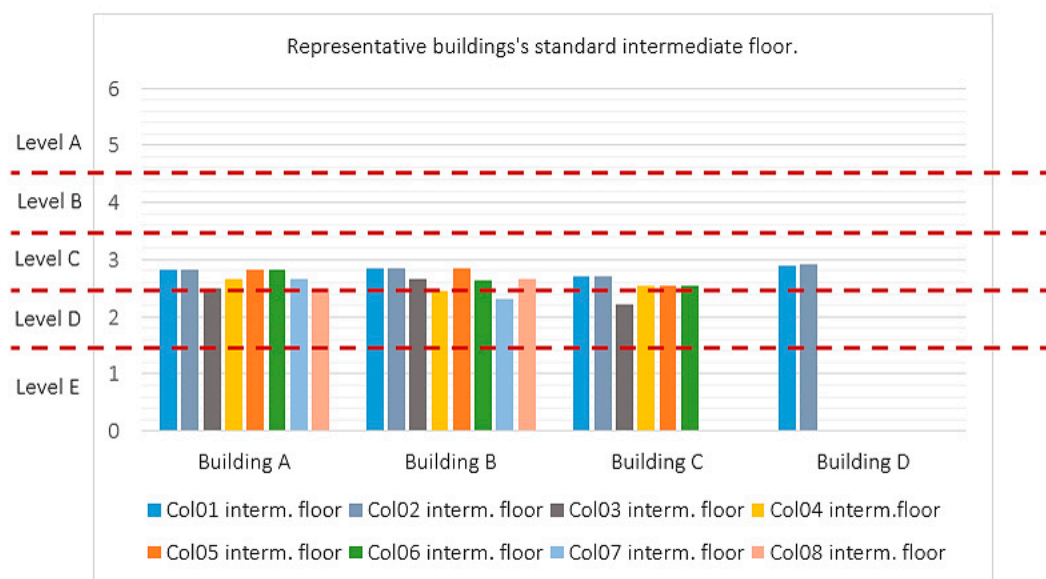


Figure 8. Final classification of the HU (standard intermediate floor) with the water heating system.

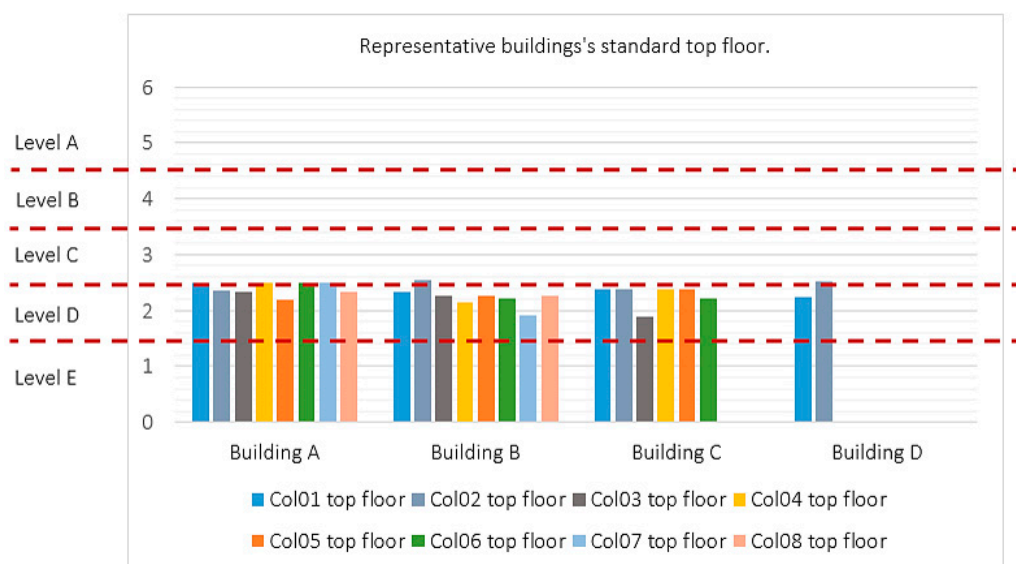


Figure 9. Final classification of the HU (standard top floor) with the water heating system.

The four building typologies representing the Jardim Camburi neighborhood in Vitória were all classified as C using the prescriptive method of the RTQ-R. Table 9 shows that both the PMV (Prefeitura Municipal de Vitória), Vitória City Hall, -approved buildings in 1981 and the newer ones (1996 and 2012) have similar numerical equivalents.

Table 9. Final classification of the representative multi-family buildings using the RTQ-R.

Representative Building	Numerical Equivalent in Current Building Situation	Multifamily Building Efficiency Level
A	2.61	C
B	2.53	C
C	2.51	C
D	2.84	C

4. Conclusions

The approval of the National Energy Conservation Policy and the creation of the National Program for Energy Efficiency in Buildings (Procel Edifica) attract researchers from different regions of the country, highlighting the contributions of LabEEE. The application of the RTQ-R has been studied in undergraduate and graduate academic courses. Several studies have considered the importance of the partnership between the real estate market and academia, discussed how the labeling process provides indicators for the consumer, and presented successes and areas for improvement within the regulation.

For the analysis and data collection of the representative buildings, it was essential to visit the buildings and get access to documentary and photographic records of the current situation of the buildings and information about the elements of the wall composition and coverage. This information is not always available and interviews may be conducted with residents /managers who have already renovated or maintained the buildings. Another difficulty is defining the absorbance of the external wall cladding, as its colors are usually defined visually and the absorbance is referred to in the RTQ-R general Annex V, using the closest approach and considering the paint finish. There are devices that make this measurement, however they are not as available for rent or loan. The prescriptive method meets simpler geometric shapes, such as the four buildings studied. However, for more complex forms, it is understood that computer simulation is more appropriate.

In fact, RTQ-R calculations are complex and there is a lot of data to feed it. However, the study of academic research on the topic, the information and manuals available in the PBE Edifica virtual environment, and the consultation of the forum, also available on the PBE Edifica portal, help to broaden the process compression. The use of the editable spreadsheet developed by LabEEE contributes to simplify the process of calculating the efficiency level of the UHs, favoring the application and understanding of the method.

The building typologies selected to represent the buildings of the Jardim Camburi neighborhood in Vitória, ES, all presented the same level of energy efficiency in their classification as multi-family buildings. Considering that the classification of the efficiency level varies from A to E, level C represents an average efficiency. Buildings B and C had very similar numerical equivalents, even though building C was 15 years newer than B. Buildings A and B are 31 years older than Building D, that means to say that buildings still use practically the same design and construction methodology, with no significant considerations for improving energy efficiency. Remembering that the RTQ-R calculation method is the same, indifferent of the building age.

Obtaining the classification C is also conditional on whether it conforms to the requirements for thermal transmittance, thermal capacity, solar absorbance, ventilation, and natural light. The calculations for the representative buildings assumed that they all had the same roofing composition, which does not meet the requirements for BZ 8, and none met the minimum ventilation percentage in all EUSs. The graphical representations show that even if most spaces in an apartment are classified as B, without fulfilling one of the requirements, the envelope for the summer performance will be classified as C at best.

The capacity for individualized water measurement appears only in the building approved by the PMV in 2012. The water conservation mechanisms and equipment were not very expansive: Toilets with attached boxes in all four buildings and faucet aerators in two buildings were identified. The representative buildings do not have graywater reuse systems, rainwater collection, solar water heating, or photovoltaic panels for energy cogeneration. In addition, in the survey of the 663 buildings, few roofs were identified with solar panels. The graphical representation of building A shows how the electric water heating system influences the final HU classification. In general, with regard to the envelope performance for summer, floors on stilts are more efficient than are intermediate or top floors. The relative refrigeration (artificial cooling) consumption for some bedrooms on the top floor is more efficient than those in the same column on intermediate floors and on stilts, which suggests that further research on this aspect is required.

Considering that the studied buildings in the Jardim Camburi neighborhood are of similar type to most residential buildings in the country with four or more floors, the results of this study, as well as those of Matos (2012) and Triana et al. (2015), suggest that the minimum standards of the current buildings are not sufficient to achieve a good thermal performance. Based on the results, some recommendations can be made:

- Reference should be made to Procel Edifica when developing plans related to construction and the Institution's approach to regulations; a reference to Procel Edifica should also be made to technical committees that involve unions, class entities, and companies in the sector.
- Additional academic studies in this area should be conducted to deepen the analysis and contribute to the dissemination and application of the RTQ-R.
- New construction compositions for roofing, such as tensioned flat slabs, painted roofs, and aluminum thermal blankets should be added to Annex V of the RTQ-R.
- The shading variable score on the types of shading elements for openings on the east façade in BZ 8 should be reviewed since blinds that completely cover the opening when they are closed receive a score.
- State and Municipal Governments should work in closer collaboration with the National Energy Conservation Policy and Procel Edifica.
- Governments should use energy efficiency program planning tools by combining physical construction data with empirical research data on housing and building operating data, estimating energy consumption for different scenarios, and encouraging energy efficiency in buildings.
- Bodies that fund the building and are responsible for policies for the Brazilian Social Housing Program should require the use of PBE Edifica labeling in their projects to establish minimum standards of energy efficiency in the sector and as a way to stimulate the practice of labeling among builders and designers.
- The construction industry should seek a long-term investment perspective, not only based on minimum and immediate construction costs but also considering the life cycle of the building.
- Designers and specifiers of construction materials and processes should consider bioclimatic zones and introduce measures of energy efficiency into buildings, including revised construction typologies.
- Designers should consider openings (natural lighting and ventilation), colors of exterior walls, roofs, and ceilings of the EUSs (absorbance and reflectance), porosity and cross ventilation, composition of walls and roofing (thermal transmittance), shading elements, water solar heating, water conservation equipment, individualized water and energy measurements, graywater reuse systems, and rainwater collection.

The results presented will hopefully contribute to a better understanding of the application of the RTQ-R prescriptive method regarding the design and construction process variables that influence the energy efficiency and thermal performance of apartments. Designers are also expected to evaluate their building designs and specifications of materials and processes within the framework of the technical regulations proposed by PBE Edifica, and committees developing urban laws should also consider such criteria.

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