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The implementation of energy regulations is the strategy most often used by governments to improve the energy efficiency of buildings. Based on Brazilian government incentives initiated in 2001 with Law 10.295, which regulates the National Policy for Conservation and Rational Use of Energy, Brazil has begun to develop methodologies for evaluating the energy efficiency of buildings. In February 2009 the Brazilian Energy Labeling Schemes for Commercial, Public and Services Buildings (RTQ-C) was published followed by the Brazilian Energy Labeling Schemes for Residential Buildings (RTQ-R) in November 2010. This article presents the methodology adopted by RTQ-R, the primary focus of which is the evaluation of naturally ventilated buildings, bioclimatic strategies for encouraging natural ventilation and daylighting, and evaluation of the water heating system. It also presents a review of House Energy Rating Schemes and shows the difference between the Brazilian Scheme and those applied by other countries. These differences are discussed and assessed herein.

Keywords: Bioclimatic strategies; Brazilian labelling scheme; energy efficiency; regulation; residential buildings

Introduction

Increasing energy consumption per capita is a reality in both developed and developing countries and is becoming one of the main issues confronting the world's economists at the regional, national and international level. Population growth, construction sector growth, and the higher levels of comfort and increased time spent inside buildings indicate that the upward trend in energy demand will continue well into the future (Iwaro and Mwasha 2010).

The contribution of buildings to the growth in energy consumption exceeds that of important sectors such as industry and transport, raising concerns in relation to government procurement, and the preservation of and access to energy resources (Pérez-Lombard *et al.* 2009). In Brazil, the industrial sector has the highest energy consumption, amounting to 44% of the total. However, in combination, residential, commercial and public sector buildings consume 47% of the total use, thus surpassing consumption by the industrial sector (BEN 2010). The residential sector currently accounts for 24% of the country's electricity consumption and has grown on average by 5.7% per annum between 1975 and 2009 (BEN 2010). Among the notable factors contributing to this growth rate are rising incomes, an increasing number of households, reactivation of the credit system and creation of small businesses (informal market) in residences (EPE 2006).

The adoption of regulations governing the application of conservation measures in new or existing buildings is one of the strategies that provide high energy savings in the building sector. Building assessment methods are being developed in several countries in order to analyse and classify building performance. The main methods consider energy efficiency as a performance indicator, because energy represents a large part of the operating costs, and energy efficiency has a high impact on the visual and thermal comfort of occupants and has the potential to provide consumers with information on future energy costs (Kordjamshidi and King 2009).

In developed countries, the first statistical data on the energy consumption of buildings appeared in the 1970s. Investigations into the energy consumption of buildings in the United Kingdom and energy auditing of homes in the United States were initiated around this time (Chen *et al.* 2008).

The first regulations relating to the thermal performance of buildings emerged in Europe in the early 1970s and defined the parameters for the building envelope, in order to reduce heat transfer through its construction components. Following the appearance of these regulations, improvements in design practices were instituted aimed at the thermal control of buildings (Pérez-Lombard *et al.* 2009). In the early 1990s, regulations and energy certification for buildings emerged as a new way to

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reduce energy consumption and greenhouse gas emissions. These regulations set minimum acceptable energy efficiency requirements for new buildings. The main objective was to conserve energy and reduce related parameters (such as primary energy consumption, CO_2 emissions and energy costs) without compromising the comfort, productivity or quality of building architecture. Despite these regulations, energy consumption is still growing mainly due to population increase and development acceleration of some countries (Figure 1). Developing countries such as Brazil and China consume less energy per capita compared to developed countries (Figure 2). However, as a result of development, Brazil will increase its energy consumption. To prevent an excessive increase, an alternative approach is the use of passive strategies in buildings such as natural ventilation to minimize the use of air conditioning.

In Brazil, the first procedures related to energy conservation emerged during the energy crisis that occurred in 2001. Law No. 10.295 of 17 October 2001, which provides the National Policy for Conservation and Rational Use of Energy (BRASIL 2001), establishes the need for 'technical indicators and specific legislation' aimed at the rational use of energy in buildings.

Thus, in late 2005, TG-Buildings created the Buildings Technical Secretariat (TS-Buildings) to discuss issues related to the technical requisites and building energy efficiency indicators. TS-Buildings was established as a forum for discussions that involved several experts from academia and representatives of the boards of the relevant entities and the construction industry. It is coordinated by PROCEL Edifica (Brazilian Program for Electricity Conservation in Buildings). PROCEL Edifica aims to lay the foundations

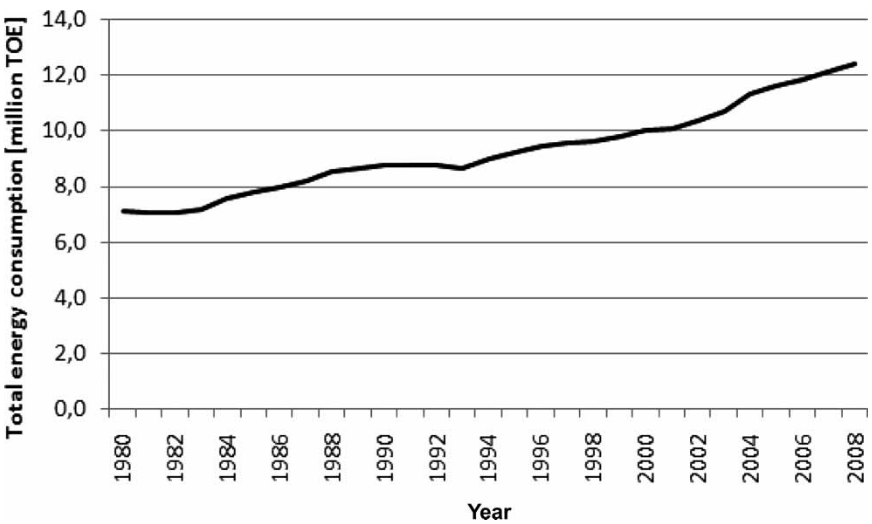

Figure 1. Global energy consumption.
Source: Adapted from EIA (2011).

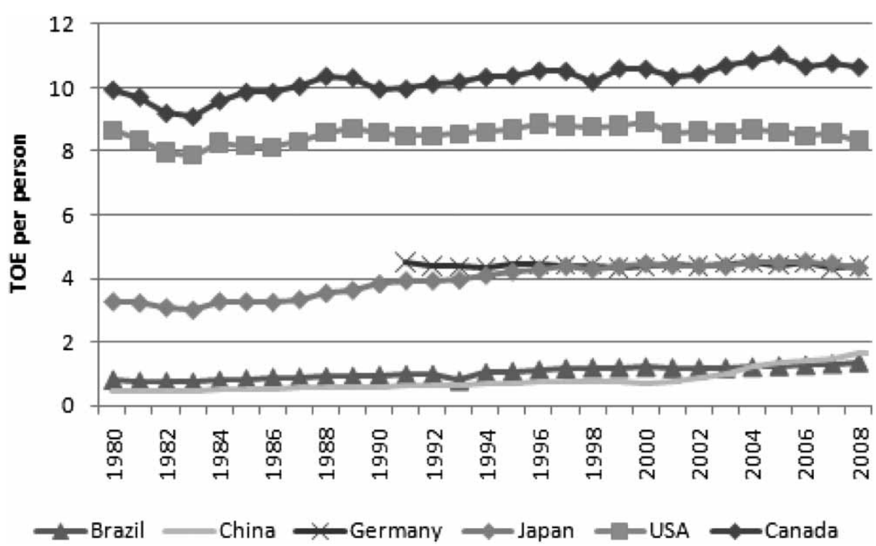

Figure 2. Primary energy consumption in different countries. BTU converted to TOE (tonnes of oil equivalent). 1 TOE = 41.86×10^9.
Source: Adapted from EIA (2011).

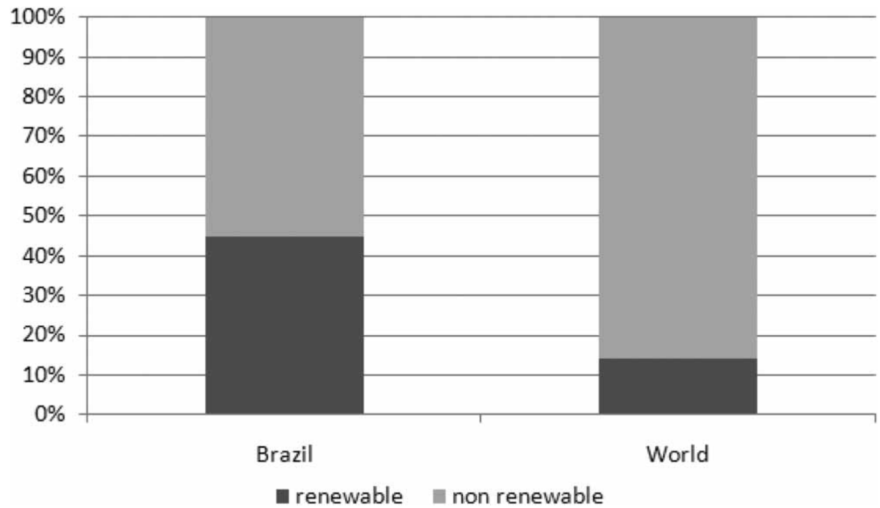

Figure 3. Energy matrix in Brazil and the world.
Source: Adapted from EIA (2011).

necessary to rationalize energy consumption in Brazilian buildings and, as one of its areas of action, to support the development of reference parameters to verify the level of energy efficiency of buildings. As a result, in February 2009 INMETRO (National Institute of Metrology) published the first version of the Brazilian Energy Labeling Schemes for Commercial, Public and Services Buildings (RTQ-C) (BRASIL 2010a) and in November 2010 the Brazilian Energy Labeling Schemes for Residential Buildings (RTQ-R) (BRASIL 2010b), which is the focus of this article. The application of both regulations is on a voluntary basis.

RTQ-R specifies the technical requirements and methods for classifying the level of energy efficiency of residential buildings, allowing the National Energy Conservation Label to be obtained. The purpose of RTQ-R is to create conditions for labelling the level of energy efficiency of autonomous housing units (dwellings or apartments), multifamily residential buildings, and common areas of multifamily buildings or condominiums. The assessment of emissions is not included in RTQ-R since the Brazilian energy matrix is based on renewable sources (Figure 3).

House Energy Rating Schemes (HERS)

Throughout the world, the residential building sector is seen as a significant contributor to energy consumption and hence to the emissions of gases that cause global warming. According to Kordjamshidi (2011), these buildings have been found to be responsible for emitting around 15% of greenhouse gas emissions in OECD (Organization of Economic Co-operation and Development) countries such as Australia (Harrington *et al*. 1999), the UK (Office of the UK Deputy Prime Minister 2004) and the US (United Nations 2004). Furthermore, the energy end-use in this sector has been growing. The IEA (2007) estimated that residential energy end-use will rise by an average of 1.7% per year. For this reason, the residential sector has been the focus of policies in several countries.

The provision of regulations is one of the political actions aimed at reducing energy consumption, and for this purpose it is necessary to adopt a methodology for assessing the level of energy efficiency. Currently, different methodological approaches can be identified.

In the United States, the concern for reducing energy consumption was translated into action through the Energy Policy Act in 1992 (US 1992). This federal law determines that prefabricated buildings need to guarantee at least the recommendations of ASHRAE 90.2 (Energy Efficient Design of Low-Rise Residential Buildings ANSI/ASHRAE 2007) for thermal insulation and energy efficiency.

From the Energy Policy Act, regulations for residential buildings were developed such as the California Home Energy Rating System Program Regulations prepared by the California Energy Commission (1999). The latest version of these regulations (California Energy Commission 2009) assesses the efficiency level of a residence through the California HERS Index, which is based on the energy consumption of the building.

The Californian regulations and others applied in the US assess the level of energy efficiency of buildings according to energy consumption, for example they consider the buildings artificially conditioned.

In Australia, the Nationwide House Energy Rating Scheme (NatHERS) also evaluates the level of energy efficiency of buildings as being artificially conditioned. This regulation gives houses a rating of up to five stars, according to their design, heating and cooling energy requirements.

In relation to the consideration of buildings as being artificially conditioned, natural ventilation, not mentioned in the regulations of the two above-mentioned countries, could be used to minimize the use of air conditioning. Specifically regarding NatHERS, according to Kordjamshidi (2011), some authors (Soebarto 2000; Williamson 2000) believe that the regulation is limited because it ignores the significance of architectural design as a passive means of ensuring energy efficiency. NatHERS relies on constant indoor 'comfort temperature' performance.

In Europe, the regulations use energy consumption as a methodology. The European Union signed an agreement within the Kyoto Protocol that obliges countries to define courses of action to encourage the use of energy resources in a rational manner, thus reducing CO_2 emissions. To meet this commitment, a series of requirements for improving the energy performance was created by the European Directive on the Energy Performance of Buildings. All member states have to set standards for energy efficiency in new buildings based on the energy performance of the building, according to this directive (IEA 2008). The performance has to take into account the building shell, including air-tightness, heating and cooling installations, orientation and position of the building, ventilation, passive solar systems and solar protection, and indoor climate according to the annex of the directive (IEA 2008).

Following the European Directive, Portugal adopted its national regulation in 2006. Regulation Characteristics of Thermal Behaviour of Buildings has elements of the envelope, thermal bridges and solar factor as minimums for the thermal quality of the envelope. Energy requirements are the energy needs for heating, cooling and domestic hot water and the global nominal primary energy. In addition to these requirements, solar collectors are required.

In the final equation, the weighting for the water heating system is considerably larger than those for the other variables. In this regard, the designer can easily change the classification of the building through changes in the system specification without changing the design. In some cases, placement of insulation on the surface may not achieve a change of class. Nevertheless, it is noteworthy that the thermal conditioning requirements for the envelope in compulsory standards already guarantee good thermal performance.

Regulations in both Australia and Europe use energy consumption as a basis for assessing the level of energy efficiency. In contrast, the evaluation of envelope performance in Brazil (RTQ-R) is aimed at encouraging the use of bioclimatic strategies such as natural ventilation and natural lighting.

Brazilian Energy Labeling Schemes for Residential Buildings

The energy efficiency classification of dwellings in Brazil is based on an evaluation of the thermal performance of the envelope and water heating system. Both individual systems and the overall rating range from level 'A' (most efficient) to 'E' (least efficient). Figure 4 illustrates a dwelling label in bioclimatic zone 3 (e.g. city of São Paulo).

Evaluation of the envelope of residential buildings

The evaluation of the envelope is based on performance requirements and prerequisites that must be met in order to maintain the level achieved. As prerequisites, the regulation provides maximum transmittance as a function of thermal capacity levels and solar absorptance of the walls and roofs, and minimum percentage for openings for natural lighting and ventilation, according to the bioclimatic zone where the building is located.

Brazil has eight bioclimatic zones (Z) as shown in Figure 5. Zones Z1 and Z2 represent the colder regions and Z7 and Z8 represent the warmer regions of the country. In Table 1 the design strategies for each bioclimatic zone are described.

Some of the prerequisites relate to ambient conditions and others to the dwelling. If a room has less than the minimum percentage of opening for ventilation or exceeds the limits of transmittance as a function of thermal capacity levels and solar absorptance, the efficiency of its envelope reaches a maximum level 'E' because it does not meet the prerequisite.

The envelope performance also varies according to the bioclimatic zone where the building is located. The assessment, rather than considering the dwelling as a whole through the fulfilment of requirements related to the building parameters, is performed by considering prolonged-stay environments, providing greater flexibility of the method by addressing a range of issues from exposure to external façade orientation of each environment. Thus, the envelope of each environment receives an energy efficiency level and the weighting of the energy efficiency level for each environment results in the classification of the dwelling envelope.

The envelope efficiency level for summer is obtained for each of the eight bioclimatic zones by determining the indicator for cooling degree hours, which indicates the degree of discomfort hours. This indicator is defined as the sum of the hourly temperature difference, when it is above a base temperature. The base temperature was defined using ISO 7730/2005 criteria.

The comfort limits for the operating temperature were obtained from the ISO 7730/2005 criteria for light activities (70W/m^2 of skin area) in summer conditions (cooling period) considering the thermal insulation of 0.5clo and operating temperature up to 26°C. A fixed temperature of 26°C was used instead of an adaptive comfort temperature in order to better show the difference between solutions that can have a better performance if the user decides to use an HVAC system.

Calculation of the cooling degree hours was based on an operating temperature of 26°C, meaning that periods when the operating temperature of the environment is above 26°C are added to the total cooling degree hours. Although adaptive comfort permits higher temperatures, the temperature of 26°C was adopted to differentiate buildings that

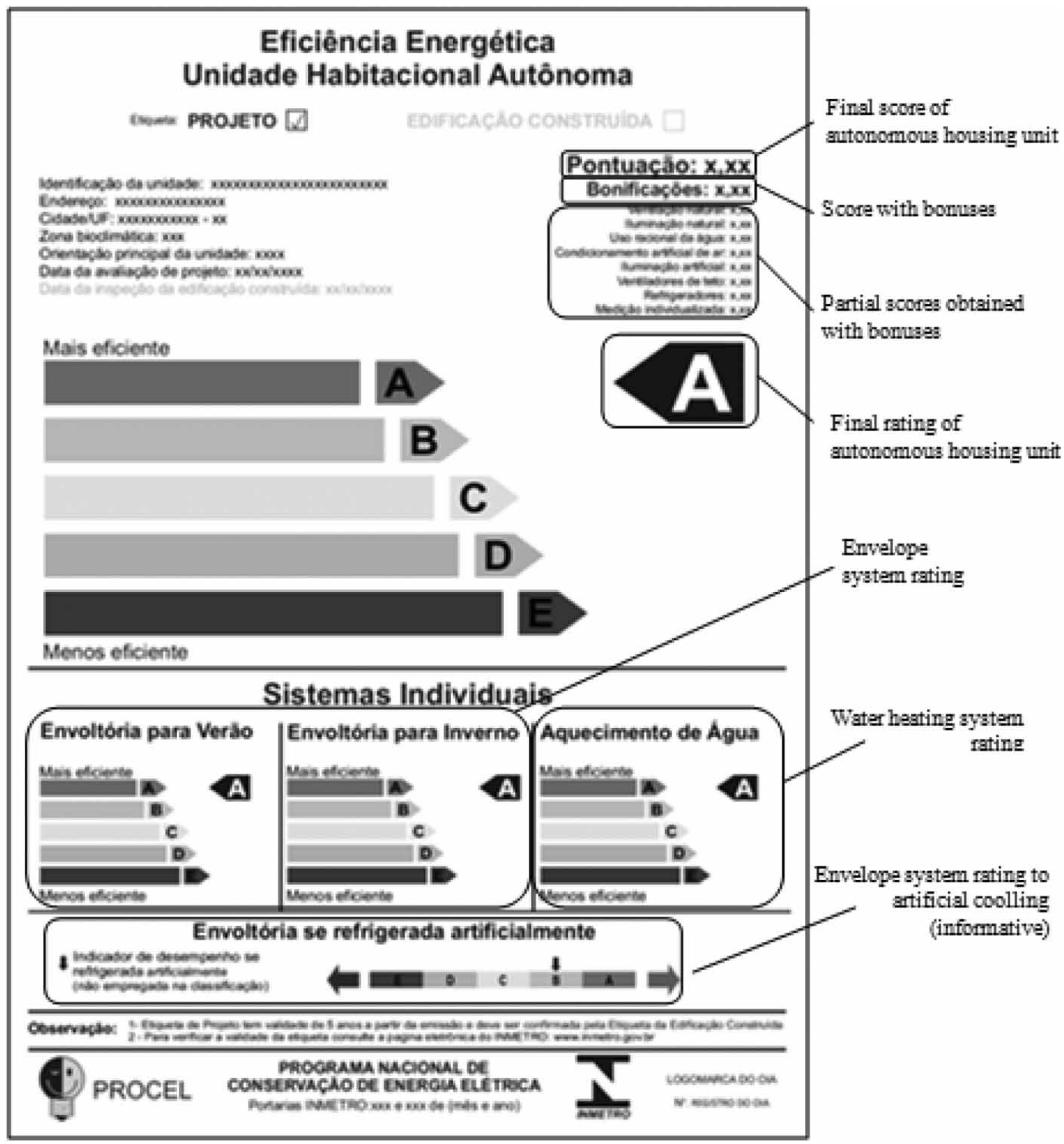

Figure 4. Example of dwelling label energy efficiency in bioclimatic zone 3.

have better performance and would use less artificial air conditioning, if desired by the user. People have access to air conditioning in cars and at work, and sometimes also feel a need for them in their homes: they are getting addicted to artificial air conditioning. Attempts to avoid street noise also encourage the use of artificial conditioning.

The method based on cooling degree hours is indicated as a simple way of analysing the thermal performance of buildings. In general, it can be used to estimate the annual cooling load for a year or a shorter period. Thus, this method is a good indicator for analysing the thermal performance of naturally ventilated residential buildings as it allows consideration of the operating temperature conditions in environments without artificial air conditioning.

In addition to the summer performance envelope, that for winter is assessed in bioclimatic zones 1–4 through the indicator of energy consumption for heating. This indicator represents the total energy consumed in 1 year for space heating, in kWh/m^2 year. For bioclimatic zones 5–8, no measure of performance for heating was adopted because the consumption of electricity for heating the air was insignificant or null.

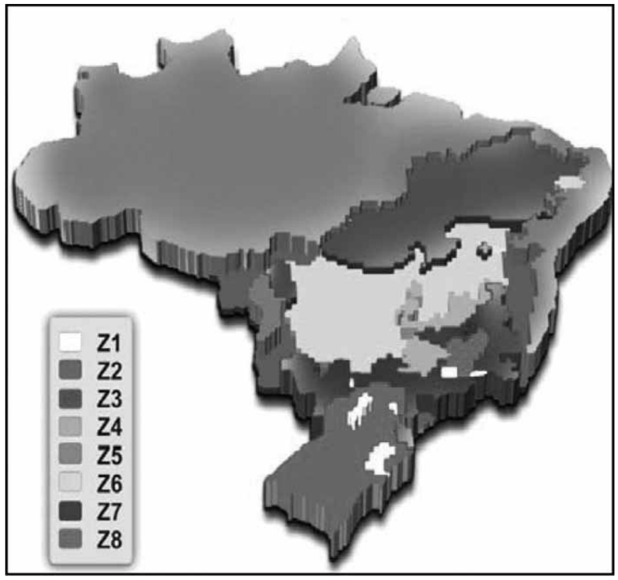

Figure 5. Brazilian bioclimatic zones defined in NBR 15.220-3.
Source: CAIXA (2010).

Table 1. Strategies for bioclimatic zones in Brazil (NBR15220-3, 2005).

Zone	Summer	Winter
Z1		Direct solar heating Heavy internal walls (thermal inertia)
Z2	Cross ventilation	Direct solar heating Heavy internal walls (thermal inertia)
Z3	Cross ventilation	Direct solar heating Heavy internal walls (thermal inertia)
Z4	Evaporative and thermal mass for cooling Selective ventilation (when the temperatures are beneficial)	Direct solar heating Heavy internal walls (thermal inertia)
Z5	Cross ventilation	Heavy internal walls (thermal inertia)
Z6	Evaporative and thermal mass for cooling Selective ventilation (when the temperatures are beneficial)	Heavy external walls (thermal inertia)
Z7	Evaporative and thermal mass for cooling Selective ventilation (when the temperatures are beneficial)	
Z8	Permanent cross ventilation	

Initially, the annual totals for the cooling and heating degree hours were adopted as performance indicators. However, the indicator for heating degree hours did not respond satisfactorily to some climatic conditions, because it did not reach values that allow a comparison between different cases. To solve this problem, the sum of the heating degree hours was replaced by the energy consumption for heating. This consumption, even when the environments are not artificially heated, serves as an indicator of performance because the ventilation openings are mostly closed in the winter, and thus the consumption for heating is a good indicator of envelope performance (Versage 2011).

The performance of the envelope can be determined from two methods: the prescriptive method and the simulation method.

The prescriptive method consists of equations that limit the parameters of the envelope. The equations were developed from multiple regression equations based on more than 150,000 cases simulated in EnergyPlus (Versage 2011), representing more than 3000h of computer simulation.

Multiple linear regression is a statistical method that considers the relationship between multiple variables, so that one variable can be estimated or predicted from the other. For the prescriptive method, the statistical method of multiple linear regression was used for the preparation of equations to predict an index of energy efficiency from the constructive, thermal and geometric parameters of one environment (Versage 2011).

The equations of the prescriptive method that allow the indicators to be obtained were developed through multiple linear regression models, in which one variable is predicted as a function of several predictor variables. The indicators of thermal performance and energy efficiency (cooling degree hours, relative consumption for heating and relative consumption for cooling) were adopted as predicted

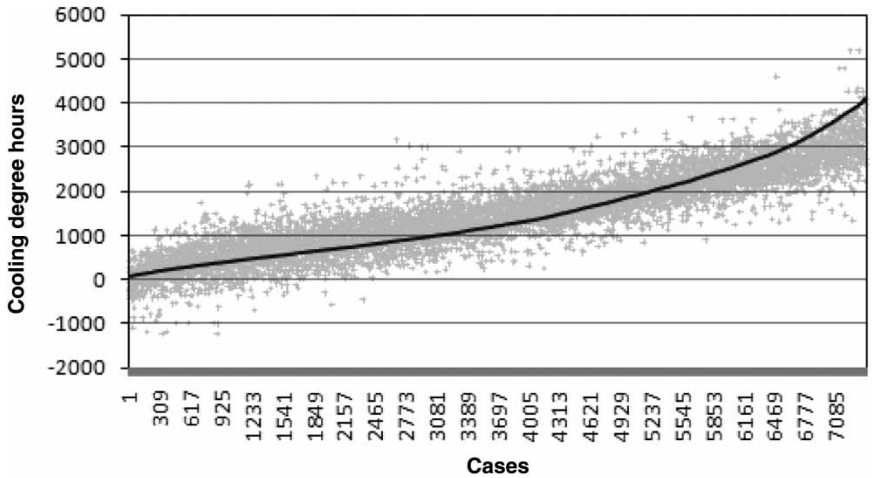

Figure 6. Compliance of predicted to simulated values for cooling degree hours in Z3.

variables. The construction parameters that can affect the thermal performance of an environment are divided into four categories:

(1) *Thermal variables*: thermal transmittance, solar absorptance and thermal capacity of building elements.
(2) *Geometric variables*: ambient areas, ceiling height, volume, wall area, glazed areas and areas open for ventilation.
(3) *Construction variables*: contact with soil, exposure of the roof, stilts, shading in the glazed areas, glazed openings with double glazing.
(4) *Combined variables*: combination of thermal and geometric variables such as thermo-geometric physical variables.

To develop the regression models, databases were constructed with the simulation results for the thermo-energy parameters of residential buildings naturally ventilated and artificially conditioned. These simulations were carried out in the EnergyPlus program for each Brazilian bioclimatic zone with the climatic records of representative cities.

To obtain these results, differences in the geometric proportions of bedrooms and living rooms, building typologies (with different transmittance, absorptance and thermal capacities of the walls and roof), solar orientation, external contact with the ground, roof and stilts were considered.

The multiple linear regression equations allow the sums of the cooling degree hours and the energy consumption for the heating and cooling of an environment to be predicted, and these are used as indicators of thermal performance and energy efficiency. These indicators are divided into a scale that classifies the environment analysed on a scale of ‘A’ to ‘E’.

However, these multiple regressions have limitations, such as a sometimes high standard error, that result in uncertainty and imprecision being associated with the method. Other statistical methods are being tested. The graph in Figure 6 shows the adherence of cooling degree hours values predicted by the regression to the simulated values for the cooling degree hours for bioclimatic zone 3.

In addition to these two indicators, the relative consumption for cooling is calculated for all zones, which represents the annual electricity consumption for air cooling, in kWh/m^2 year. In this analysis the possibility of changing the indicator from kWh/m2 year to kWh/year is better because it is related to efficiency according to the function (of the room). As an example, let us assume two bedrooms with different areas: one with 15m^2 and the other with 60m^2. If the consumption of the 15m^2 bedroom is 120kW/year and that of the 60m^2 bedroom is 400kW/year, the 60m^2 bedroom consumes 3.3 times more energy than the 15m^2 bedroom to provide the same function. But if the kWh/m^2 year indicator is used, then the 60m^2 bedroom consumes 6.6kW/m^2 year and the 15m^2 bedroom consumes 8.8kW/m^2 year. Thus the 60m^2 bedroom, notwithstanding consuming 3.3 times more energy, appears to consume 1.3 times less energy than the 15m^2 bedroom. This indicator is used to evaluate the performance of the envelope when it is artificially cooled and was developed for all bioclimatic zones. However, the indicator is for informational purposes only and does not affect the overall classification for the envelope.

In the simulation method, the performance of the building envelope is determined by computer simulation. This is carried out to model the geometry of the building under evaluation and perform simulations for two conditions: one for the naturally ventilated building ventilation network and the other for the artificially conditioned building, as described in the requirements of RTQ-R. The simulation method compares the performance of the building under evaluation with the tabulated reference values for the energy efficiency levels of envelopes, available at Procel Info (PROCEL Info 2011).

Figure 7 shows an example of the relative cooling degree hours and the energy consumption for air conditioning for buildings in different locations, where, for the same case,

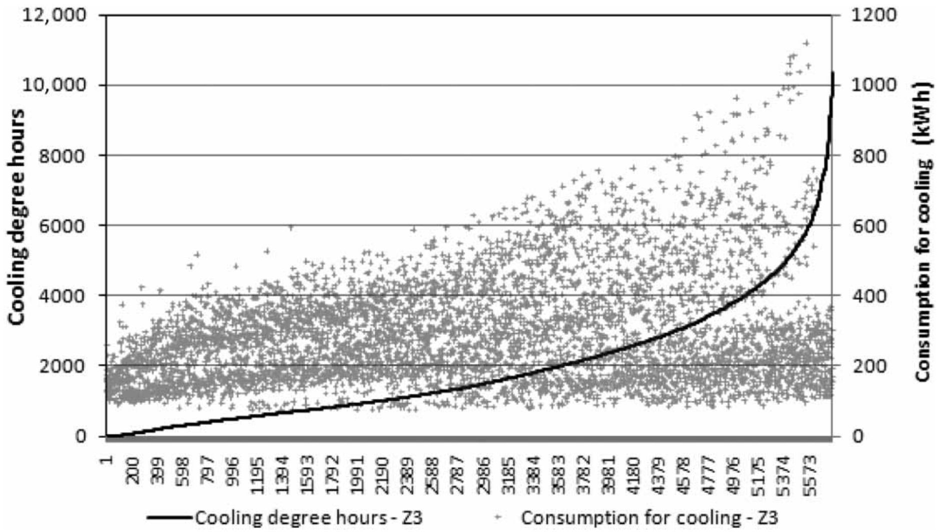

Figure 7. Comparison of cooling degree hours and consumption for cooling to Z3.

there isn't the same performance trend for both indicators. Therefore, energy consumption does not serve to indicate the performance of buildings with passive design strategies. Using consumption as a performance indicator can be encouraged to build homes that do not work well naturally conditioned.

Water heating assessment

The water heating criteria were determined for the evaluation of solar heating systems, gas systems, heat pumps, electrical resistance and oil boilers. Higher levels of efficiency (A or B) can be achieved with the use of one of the first three systems (each system has a different assessment method). In contrast, systems for electrical resistance reached a maximum level D and boilers that use liquid fluids such as diesel or other petroleum derivates reached a maximum level E.

For solar and gas systems, the proper sizing of the system is evaluated in an attempt to avoid under- or overestimation, and also the equipment used: solar collectors and tanks and gas equipment should be included in the Brazilian Labeling Program and should achieve levels A or B. Heat pumps are evaluated according to the coefficient of performance of the equipment.

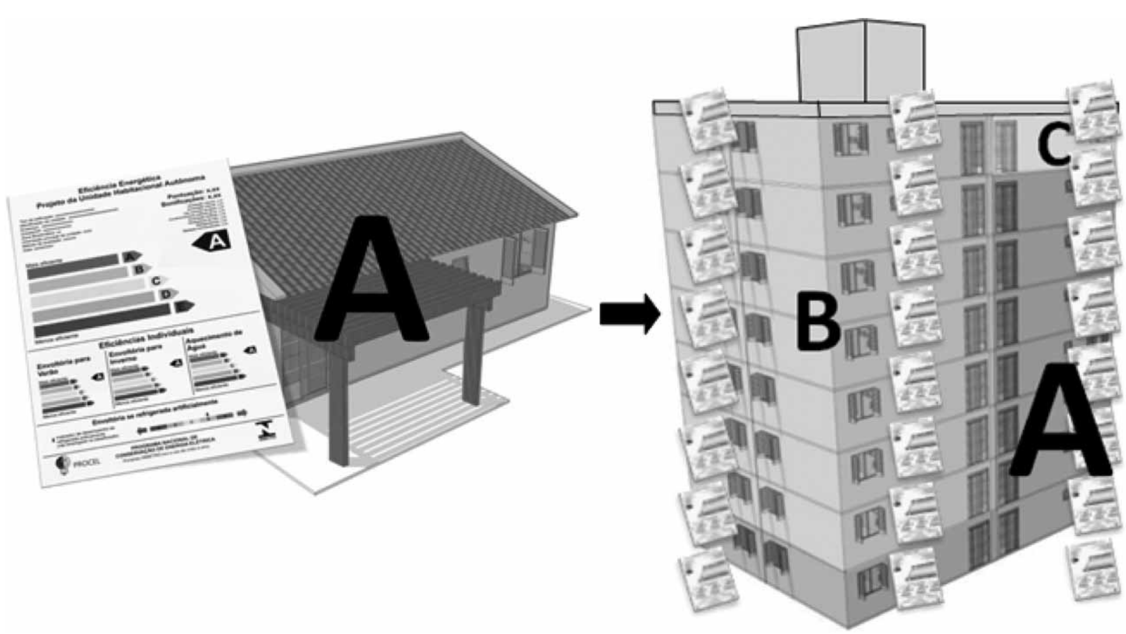

Figure 8. Multifamily building classification.

The weight of water heating level of efficiency varies according to geographic region. In areas where heating demand is greater (south and southeast regions), the weight will be 35%; whereas in areas where need is less (north, northeast and midwest), the weight ranges from 5 to 10%.

Building classification

Weightings are assigned to the results for the summer and winter envelope classification (only in the case of bioclimatic zones 1–4) and the efficiency of the water heating system, according to geographic region in which the building is located. To the classification a bonus point can be added, which can be obtained for implementing natural ventilation and lighting strategies that are more advanced than those present in the prerequisites, the use of efficient light bulbs, refrigerators, air conditioners and ceiling fans, and the use of individual hot water metering. The bonuses are present in the regulation in order to encourage more efficient practices.

For bioclimatic zone 3, for instance, the weightings are 42% envelope for summer, 23% envelope for winter and 35% water heating. In extreme bioclimatic zones 1 and 8, the percentage of the envelope is different. For bioclimatic zone 1, the coldest one, 92% envelope is for winter and 8% for summer; whereas in zone 8, the warmest one, 100% envelope is for summer.

Multifamily building assessment

The classification of a multifamily building results from weighting the results of the apartments according to their floor area, as shown in Figure 8.

The multifamily building label includes information on the classification of all apartments and the general classification of the building (Figure 9).

Assessment of common areas

The assessment of the common areas of condominiums or residential multifamily buildings is divided into two areas:

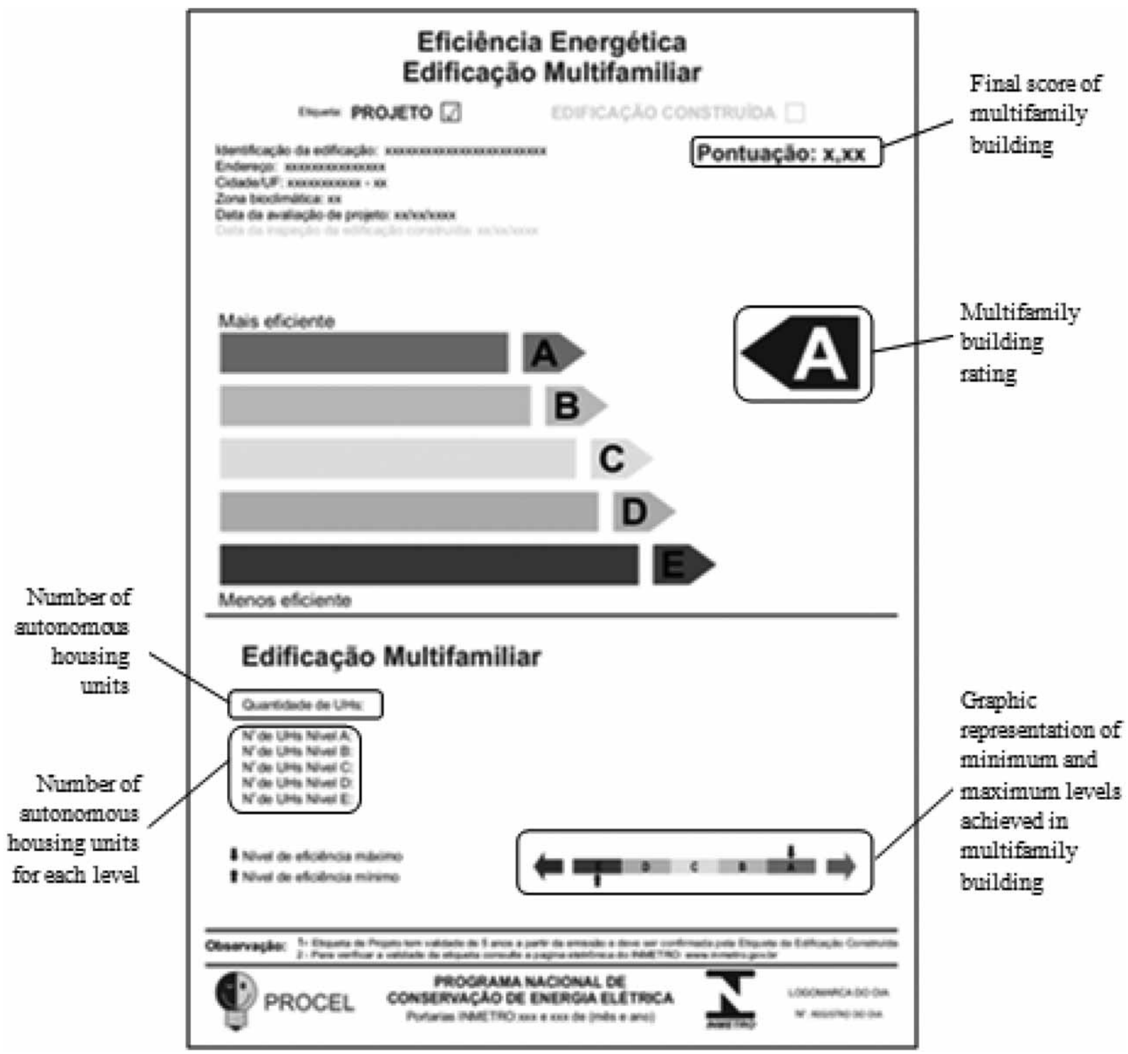

Figure 9. Example of multifamily building label.

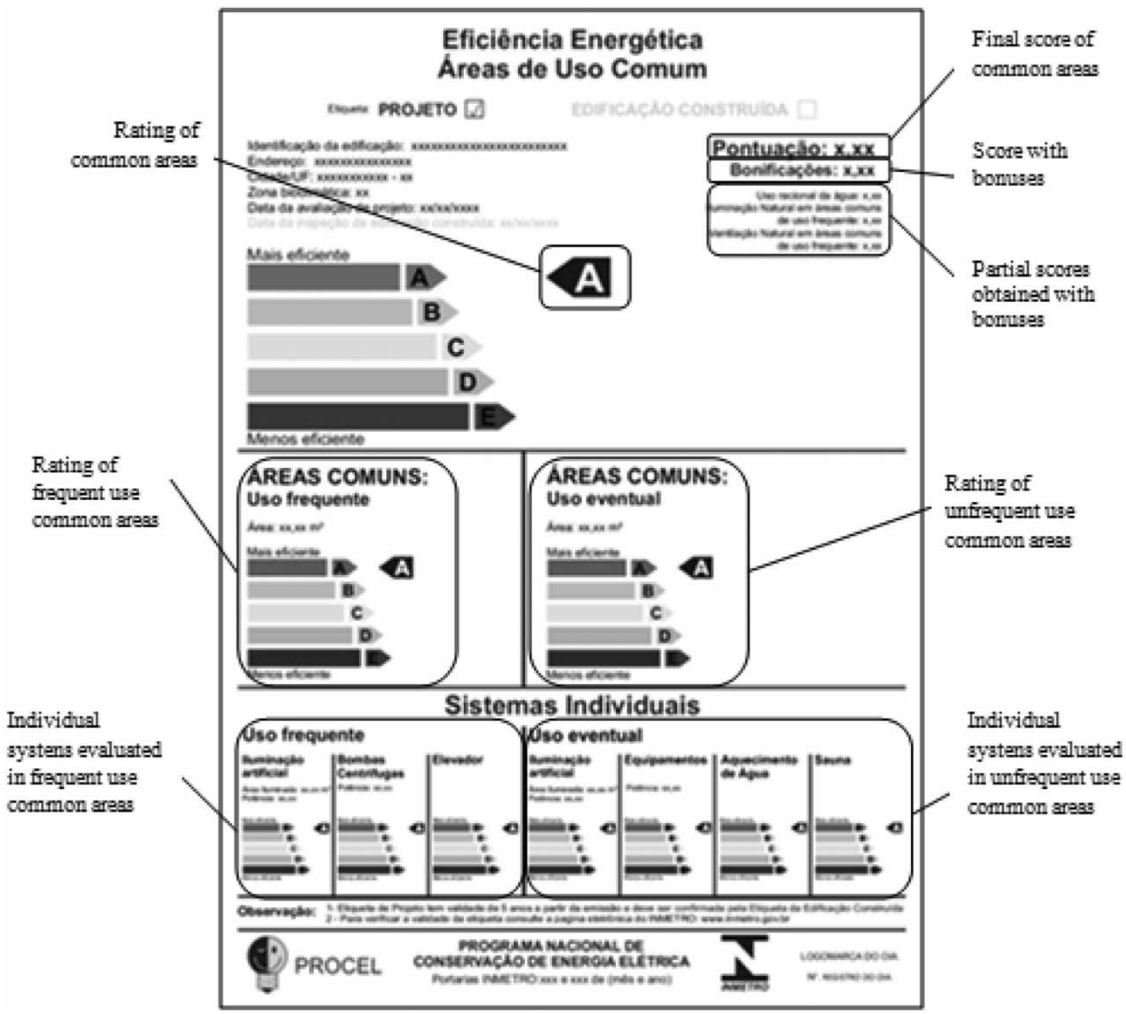

Figure 10. Example of labels for common areas.

frequent use and infrequent use. The first includes circulation area, halls, garages, stairwells, lobbies, elevators, hallways, visitors parking, external accesses and similar uses. The second considers events room, swimming pool, playroom, shared toilets, bicycle park, sports courts, cinema room, study room, gym, playground, barbecue area, sauna and other collective spaces for the leisure and recreation of residents. The proposed method allows the evaluation of buildings that have few common areas (such as circulation and garage), up to club condominiums with several collective spaces for residents related to leisure. For the final ranking of common areas, the following individual systems are evaluated, as applicable to the project under assessment: artificial lighting, centrifugal pumps, elevators, devices and appliances, shower and swimming pool water heating systems and saunas. One equation considers the results for frequently and infrequently visited common areas, adds the bonuses and provides the final score. The bonuses can be obtained through the rational use of water, ventilation and natural lighting in environments frequently used. The information given on the labels is presented in Figure 10.

Conclusions

This article presented innovations in regulations for the evaluation and classification of the level of efficiency of residential buildings in Brazil, showing key design assumptions.

The methodology proposed by the regulations encourages projects that use bioclimatic strategies, taking advantage of the climatic conditions of the region and reducing the energy consumption required for artificial conditioning. This represents an advantage compared with methodologies used in other countries, especially developed ones, whose ratings are based on reducing energy consumption and emissions of greenhouse gases related to cooling and heating systems. Thus, there is no incentive to avoid the use of artificial environmental conditioning systems.

Despite being recent and voluntary, implementation of the regulations fills a regulatory gap in Brazil, which so far has no energy efficiency minimum performance standard; however, there are still no compulsory standards in place. Evaluation of the energy efficiency of residential buildings tends to be incorporated into other government programmes such as Minha Casa, Minha Vida and Selo Azul da Caixa.

Acknowledgements

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