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Article

A Comparative Study of the Brazilian Energy Labelling System and the Passivhaus Standard for Housing

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Abstract: The ever-increasing energy demand of the residential sector has required the adoption of tighter energy standards, aiming for high energy efficiency in dwellings. In Brazil, 24 million new residential buildings are planned to be delivered by 2022 through social housing programs, which could greatly impact on the country's energy consumption. In an attempt to minimize this impact, the Brazilian Labelling Scheme for Residential Buildings (RTQ-R label) was launched in 2010 as a voluntary standard for the evaluation of housing energy efficiency. The RTQ-R label focuses on building fabric and hot water systems performances, and generates a score based on the building's energy efficiency levels. The Passivhaus standard, developed in Germany, is one of the most stringent standards and is also the fastest growing energy performance standard in the world with more than 30,000 buildings certified to date. It also focuses on building fabric but establishes a maximum energy consumption target. In this work, the authors developed a comparative review of the RTQ-R label and the Passivhaus standard as means to inform a broader debate about building codes in the context of the current calls by governments for increased energy efficiency. The findings highlighted the different nature of the standards' requirements and targets adopted, and the benefits and constraints of both.

Keywords: energy efficiency; thermal comfort; housing; Brazilian labelling; Passivhaus standard

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1. Introduction

The demand for housing in Brazil is growing at a considerable rate, and this growth is expected to continue in the next few years and greatly affect the sector's energy consumption [1]. Currently, the housing sector is responsible for around 9.5% of the overall national energy consumption [2], and if the energy consumption from related construction activities (extraction, production and transport) is also considered, this value reaches 22% of the total energy consumption [3]. In addition, the energy consumption of the housing sector exhibited a growth of 4.4% between 2010 and 2011 [4] and of a further 2.1% between 2011 and 2012 [2]. By 2023 the energy consumption in this sector is predicted to have risen by about 4.3% per year [1].

The majority of the housing energy demand in Brazil is met by electricity, which corresponds to around 43% of the overall sector's energy consumption [2]. The remaining amount is provided by firewood (27.2%), liquefied petroleum gas (26.9%, usually associate to cooking), charcoal and natural gas [2]. From the overall housing electricity consumption, about 20% is used for cooling or heating dwellings [5]. Even though the majority of households in Brazil do not currently have heating or cooling, the rise in income and standard of living are expected to raise the numbers of households that utilize active means for space conditioning as this will be within economic reach [6].

The housing sector is responsible for 22% of the overall construction activities in the country [7]. Its development has been greatly boosted in the last few years by government social housing programs such as the program entitled "Minha Casa, Minha Vida" ("My house, My Life", in English) launched in 2009. This program is pushing the development and construction of up to 24 million new dwellings by 2022 [8]. This ambitious target is likely to change the Brazilian housing scenario and to have a major impact on the country's energy consumption.

Building energy regulations and standards will therefore have an important role to play in supporting the construction of higher quality dwellings that are more thermally comfortable and energy efficient. The mandatory legal Brazilian standards NBR 15220 [9–13] and NBR 15575 [14–18], and also the voluntary Brazilian Labelling Schemes for Residential Buildings (RTQ-R) [19], are the legal instruments put in place to support this in Brazil.

In this present study, the authors developed a comparative study of the voluntary Brazilian labelling scheme for residential buildings (RTQ-R label) and the most stringent Passivhaus standard, aiming to support the argument for higher energy efficiency in Brazilian dwellings. This study also attempts to inform a broader debate about building regulations and standards in the context of the current calls by governments for increased energy efficiency. The scope of this paper is limited to outlining the differences and similarities between these two approaches and its structure comprises an overview and a comparative review of these voluntary standards. This review paper is the first part of a study that will investigate the potential benefits of adopting better insulated and more air-tight building envelopes in Brazilian dwellings.

2. The Brazilian Regulations and Standards

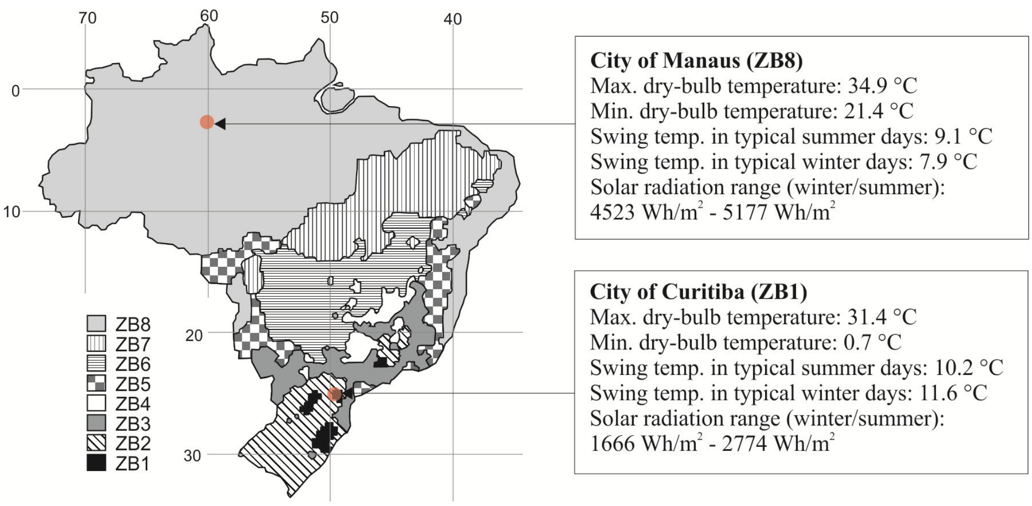
The RTQ-R label, launched in 2010, and the Brazilian Labelling Schemes for Commercial, Public and Services Buildings (RTQ-C), launched in 2009, were developed through the National Program of

Energy Efficiency in Buildings (PROCEL Edifica). They are voluntary standards that aim to support the implementation of energy conservation measures in new and existing buildings [20]. In this article, the authors deal exclusively with the residential label.

The RTQ-R label uses a methodology based on the prescription of minimum standards and steady-state calculations to evaluate the level of energy efficiency of residential buildings, taking into account the building envelope and the hot water system. It generates a rating from A (more efficient) to E (less efficient) [19]. The labelling can be supplied for different housing categories: autonomous housing units (dwelling or apartment), multifamily residential buildings and common areas of multifamily buildings (this category also included the evaluation of lighting systems and electrical equipment such as lifts) [19]. The labelling applies to naturally ventilated and air-conditioned buildings. In addition, the minimum standards prescription applies to the walls and the roof elements, and includes U-values, thermal capacity, solar absorptance and the envelope fenestration index. These prerequisites should be fully met, otherwise the level of efficiency of the envelope will receive a maximum rating of "C" [19]. The values proposed were calculated based on the Brazilian bioclimatic zones [11] and the Brazilian performance standard *NBR 15575: Residential Buildings-Performance* [14,17,18].

As can be seen from Figure 1, Brazil is divided into 8 bioclimatic zones, which are defined by the standard *NBR 15220: Thermal Performance in Buildings-Part 3: Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Houses* [11]. The areas located in the south and southeast represent the coldest climatic zones in Brazil and they are represented by the climate zone ZB1, whereas the areas from north and northeast are the hottest climatic zones and they are represented by the climate zone ZB8. To illustrate some of these climate differences, the city of Curitiba, located in climate zone ZB1 and the city of Manaus, in climate zone ZB8, were taken as an example.

Figure 1. Brazilian bioclimatic zones. Source: created by the authors based on [11].



According to the standard NBR 15575 [14], the city of Curitiba (latitude of 25.42 S, longitude of 49.27 W and altitude of 924 m), for given typical summer days, has a daily maximum dry-bulb temperature of 31.4 °C, a daily swing dry-bulb temperature of 10.2 °C and a wet-bulb temperature of 21.3 °C. For a typical winter day, Curitiba has a daily minimum dry-bulb temperature of 0.7 °C, a daily swing of 11.6 °C and a wet-bulb temperature of 11.0 °C. The city of Manaus (latitude of 3.13 S, longitude of 60.02 W and altitude of 72 m) presents a daily maximum dry-bulb temperature of 34.9 °C, a daily swing dry-bulb temperature of 9.1 °C and a wet-bulb temperature of 26.4 °C. For typical winter days, Manaus has a daily minimum dry-bulb temperature of 21.4 °C, a daily swing of 7.9 °C and a wet-bulb temperature of 25.0 °C. The solar radiation also varies considerably between the hottest and the coldest climatic zones. For example, the variation of the radiation for Curitiba for typical winter and summer days is from 1666 W·h/m^2 to 2774 W·h/m^2, respectively. For Manaus, the radiation ranges from 4523 W·h/m^2 to 5177 W·h/m^2, respectively.

The Brazilian standards NBR 15220 [11], NBR 15575 [17,18] and also the RTQ-R label [19] set their building envelope U-values according to the climatic zones. For the NBR 15220 [11], the U-values range from 2.20 W/m^2·K to 3.60 W/m^2·K for the walls and from 2.00 W/m^2·K to 2.30 W/m^2·K for the roofs. The NBR 15575 [17,18] and the RTQ-R label [19] adopt similar U-values, which vary between 2.50 W/m^2·K and 3.70 W/m^2·K for the walls and between 2.3 W/m^2·K and 1.5 W/m^2·K for the roofs. For the NBR 15575 [17,18] and the RTQ-R label [19], the U-values vary according to the absorptance of the material surface. Less strict U-values are used for low absorptance values, whilst stricter U-values are used for greater absorptance values.

3. The Passivhaus Standard

Whilst the Brazilian regulations and the RTQ-R label are a step forward, their levels of stringency are much lower than building energy regulations and standards in Europe, where great attention has been given on designing and constructing buildings that are highly insulated and airtight [21]. In general, many European countries have been pushed by the standard *Energy Performance of Buildings Directive* [22] and its *Recast Directive* [23] to set minimum building requirements aiming to achieve high energy efficiency levels. For example, in England there has been a maximum limit for U-values since 1965, and this has become more stringent over the years, reaching in 2010 a value of 0.30 W/m^2·K for the walls and 0.20 W/m^2·K for the roofs, 0.25 W/m^2·K for the floors and 2.00 W/m^2·K for the windows and the doors [24,25]. Revised values have been proposed by the 2012/13 *Part L Consultation on Changes to the Building Regulations* [25] and the fabric U-values are expected to become even stricter in 2014 when compared to the current 2010 England regulation. The current maximum airtightness in England is 10 m^3/h/m^2 at 50 Pa, as verified with an onsite air leakage test, which applies inside the building a pressure of 50 Pa above and below the ambient atmospheric [26]. It should be stressed that 1 m^3/h/m^2 at 50 Pa is equivalent to 1 ach at 50 Pa for a particular building volume of 6 × 6 × 6 m^3 and it is not applied for other buildings dimensions [26]. Other European Countries, even with warmer summers, have also set strict requirements. For example, Portugal through the decree law *DL 80/2006* [27] sets the maximum U-values ranges from 1.45 W/m^2·K to 1.80 W/m^2·K for the vertical opaque elements and from 0.90 W/m^2·K to 1.25 W/m^2·K for the horizontal opaque elements, which varies according to the climate zone where the building is located. Glazing elements should comply with maximum solar factor coefficients, which depend on the building thermal inertia and the corresponded climate zone. The Portuguese standard also establishes a maximum air flow of 0.6 air changes per hour (ach) at atmospheric pressure. Consequently, the authors questioned whether the Brazilian standards should be aiming for higher levels of energy efficiency to safeguard the future.

The voluntary Passivhaus standard, conceived in Germany but adopted in many European countries, was chosen for this comparative study because it proposes even more robust criteria for the building fabric when compared to other mandatories European legislations. The Passivhaus standard suggests a highly insulated envelope with the adoption of U-values lower than 0.15 W/m^2 and an envelope airtightness of no more than 0.6 ach at 50 Pa, which keeps the building within a very low air permeability rate [26,28].

The Passivhaus standard was originally designed for central Europe, but many studies have been developed to support its application in warmer climates. These studies have made advances by adjusting the Passivhaus standard for warmer climates and have identified potential benefits of the Passivhaus Standard adoption for the building envelope thermal performance. The Passive-On study [29,30] for example, investigated the Passivhaus standard adjustment for warmer climates in Europe. Another study carried out by Schnieders *et al.* [31] provided an overview of the applicability of the Passivhaus standard for specific climates and also established preliminary criteria for the Passivhaus in different warmer climates. In South America, initial studies have investigated the applicability of Passivhaus in Chile [32]. The most remarkable difference between the original Passivhaus standard and the Passivhaus standard for warmer climates is with regard to the management of the summer season [29]. The findings of the studies undertaken in warmer climates demonstrated that Passivhaus levels of energy efficiency can be cost-effectively achieved for these climates. The studies concluded that for these climates less effort in improving the building fabric is required compared to colder climates (*i.e.*, lower degrees of insulation).

There are also studies that have criticized the implementation of the Passivhaus standard in warmer climates such as in Brazil. One of these, just recently published [33], take a critical view with relation to the adoption of insulated and airtight fabrics, especially those linked with the Passivhaus standard. The authors argued that the insulated and airtight approach is not necessarily a suitable design strategy for hot climates found in the majority of the Brazilian regions. Even where the climate is more appropriate, for example in the Brazilian south region, the idea of airtight fabrics and sealed windows are not culturally accepted in that region, although insulation can be beneficial.

4. The Comparison Methodology

Though it is difficult to make comparisons amongst standards that do not use or measure exactly the same parameters, it is feasible to draw a comparison between them as means of exploring their opportunities and limitations [26]. For instance, the RTQ-R label evaluates the housing energy efficiency level and it focuses on energy conservation measures [20] rather than on indoor thermal comfort. The Passivhaus standard, on the other hand, assesses energy consumption and its focus on comfort and energy used during the use phase of the building because this phase is responsible for the major energy consumption impact.

Another important characteristic to take into account while evaluating national energy standards is the nature of the energy demand in those areas covered by the standard. For instance, the nature of Brazilian energy demand is different from that the Passivhaus Standard was originally designed to. The Passivhaus was conceived to achieve ultra-low energy consumption for space conditioning through a high performing envelope (tight and insulated) and by using a mechanical ventilation system with heat recovery. An effective ventilation system is essential for central Europe because the main energy demand in those countries is for heating. The Passivhaus mechanical ventilation system effectively minimizes the energy demand for space heating and it is able to recovery at least 75% of the heating to keep the building warm. It can reduce the heating demand so much that a conventional heating system may not be needed [26]. During the summer season, the ventilation system works using a bypass (without recovering the heat) and it provides fresh air to keep the indoor air quality to acceptable levels for the building occupants.

On the other hand, the RTQ-R label basically aims for improvements in the building envelope and in the water heating system. Improvements in the water heating systems are fundamental, since the Brazilian water heating for showers is mostly provided by electrical means. It is estimated that 73% of dwellings use electricity to heat water compared to only 5.9% of them that use gas and 18% of the dwellings that do not present a water heating system [5]. This scenario represents a huge impact on electricity demand, which adds up to around 24% of total appliances electricity consumption.

The other aim of the RTQ-R label is improvements in the building fabric by encouraging the use of bioclimatic strategies, which so expects to minimize the Brazilian heating and cooling demands. The national heating and cooling supplies are mainly provided by electrical means through the use of conditioning appliances, which result, on average, in 20% of overall appliances electricity consumption. The regions with higher presence of air conditioning in residential buildings are located in the north and the south, where are respectively the most humid and hottest region and also the mildest region. In the north of Brazil, cooling appliances are responsible for 40% of the appliances total electricity consumption; in the south of Brazil, cooling and heating appliances combined are responsible for 32% of the appliances total electricity consumption [5]. The presence of air conditioning systems in dwellings is still low; only 16.5% and 16.1% of dwellings in the north and south regions have an air-conditioning system, respectively [5]. However, it is expected that this percentage will increase in the next few years as consequence of the climate changes and the increased purchasing power of the Brazilian people.

5. The RTQ-R Label *vs.* the Passivhaus Standard

A recent study developed by Schnieders *et al.* [31], which analyzed the Passivhaus standard for other climates, provided a set of indicators to use the Passivhaus concepts across the world through the use of specific maps. These maps were elaborated from NASA data with average daily values of temperature, insolation and humidity over 23 years with a spatial grid resolution of one degree [31]. These findings do not exclude the simulation needs for each location, but they can orientate strategies to achieve the Passivhaus standard. Also, they are suitable for comparison purposes and they will be cited here for establishing a comparison between the RTQ-R label and the Passivhaus standard.

5.1. Primary Energy Demand

Primary energy demand considers the sum of all energy demanded by the building occupants, usually represented by the space cooling and heating demands, the DHW (domestic hot water) system demand and the household electricity demand.

The Passivhaus standard presents a mandatory requirement for the primary energy demand that must not exceed 120 $kW \cdot h/m^2 \cdot a$. In order to achieve this target, efficient household appliances and water heating systems are required [26], otherwise it is difficult to fulfil this requirement. The primary energy requirement settled by the Passivhaus standard is quite strict and it is estimated to be less than 50% when compared to common values found in conventional new European buildings [34].

The RTQ-R label does not establish similar target or comparative parameter because the aim of the label is to promote bioclimatic strategies such as natural ventilation and building fabric efficiency.

With regard to the DHW demand, the RTQ-R label strongly discourages the use of water heating systems by electrical means. The use of these systems for shower, for example, results in "D" or "E" level of efficiency, depending on the Brazilian region. Furthermore, the RTQ-R label encourages the use of solar systems and recommends that at least 70% of the total of water heating systems come from the solar sources when these systems are combined with electrical systems for achieving "A" efficiency level.

The Passivhaus primary energy target demand can be achieved all over the world, although it might need a reasonable effort, with significant investment of money and time; and also efficient household appliances may be required for hot climates as well [28,31]. Moreover, analyzing the findings of Schnieders study [31], it is feasible to fulfil the Passivhaus primary energy demand requirement, although in the Brazilian north region, where is found the most critical scenario, these target can only be achieved with some major efforts.

5.2. Space Heating or Cooling Demand and Heating or Cooling Load

The Passivhaus standard has a mandatory requirement for the space heating or cooling demand and for heating or cooling load. These mandatory requirements are that the space heating/cooling demand must not exceed 15 $kW \cdot h/m^2 \cdot a$ or the heating/cooling load has to be less than 10 W/m^2 over the day [28]. These required values have continually been investigated by the Passivhaus Institute to adapt the Passivhaus standard for other climates and higher values have been accepted for cooling demand when the cooling load is satisfied and vice versa. Currently, a provisional cooling criterion has been established by taking also into account the demand for dehumidification, which results in an increasing of the overall cooling demand. So far, the overall cooling demand requirement is established by limiting the sum of the sensible cooling demand and the dehumidification demand. The dehumidification demand is calculated based on the specific percentage of dry degree hours. More precise relation can be found in [28,31].

The RTQ-R label does not use the methodology related to the building energy consumption. The justification is that countries that rate buildings based on cooling and heating consumption actually do not have an incentive to avoid the use of the conditioning systems [20]. The RTQ-R label has adopted the methodology of cooling degrees-hour and also the methodology of relative consume for heating for assessing the envelope performance of naturally ventilated buildings. The methodology of cooling degrees-hour has been adopted to indicate the number of hours related to the cooling discomfort and the advantage of using this methodology is that it is a good indicator for assessing the thermal performance of naturally ventilated buildings because it is possible to set the operative temperature without using conditioning systems [20].

The methodology of heating energy consumption has been used as an indicator of fabric performance and it was adopted as a replacement of the heating degree-hours, which did not respond satisfactory for some climatic conditions since it does not allow comparison between different cases [20]. The heating energy consumption is an indicator for evaluating the fabric performance but do not correspond to the building real consumption [19]. The heating energy consumption analysis should be considered from the Brazilian bioclimatic zones 1 to 4, where the heating demand cannot be negligible.

Additionally, the RTQ-R label has also made use of an additional parameter, the relative consume for cooling, which has been used to evaluate envelope performance for conditioned ventilated buildings. This analysis is mandatory to obtain the certification even if the building is not designed to work with conditioning systems. The evaluation of conditioned buildings is only used for informative purposes and does not affect the overall rating of the fabric performance [19,20] but it can be valuable since the fabric achieves the "A" efficiency level in this parameter and so it can represent an additional bonus to the overall building performance analysis.

The vast majority of the Brazilian regions have exclusively energy demand for cooling and just few regions, located in the south and southeast of Brazil, present both heating and cooling needs. The exclusive need for cooling can be easy to manage in certain regions but can be more complex in climatic zones that present long periods of high temperature and high levels of humidity, such as the north part of Brazil. The findings of the Schnieders *et al.* study [31] indicate the potential sensible cooling demand and dehumidification demand in Brazil and conclude that some Brazilian regions, from the middle to the north of the country, could face difficulties to achieve an acceptable value of cooling demand that could justify a cost-effective implementation of the Passivhaus standard, although more research needs to be developed. According to this work [31] a cooling demand above 45 $kW \cdot h/m^2 \cdot a$ makes achieving the Passivhaus standard in a cost-effective way currently impossible.

5.3. Insulation—Glazing Areas and Opaque Elements

The level of insulation to be adopted to achieve the Passivhaus standard comfort requirements strongly depends on the climate where the building is designed to. The Passivhaus standard for central Europe recommends a U-value ≤ 0.15 W/m^2 for the opaque elements and a U-value ≤ 0.80 W/m^2 for windows [28]. The opaque elements and the glazing surfaces should have a compatible level of resistance to avoid the solar radiation heat to enter the building during the cooling season and to allow the solar radiation heat to enter the building during the heating season.

For the Brazilian climate, the Passivhaus study [31] seems to suggest the use of two main types of glazing, roughly represented by Figure 2. It is recommended the use of a low-e double glazing with sun protection ($U = 1.05$ $W/m^2 \cdot K$) on the south part of the country and the use of a low-e triple glazing with sun protection as well ($U = 0.6$ $W/m^2 \cdot K$) on the north part of the country. It can be noticed that less strict requirements are adopted in the Brazilian middle-south part due to the mild nature of the climate. For both double and triple glazing proposed by the study [31], it is needed a solar protective glazing to reduce transmission and solar loads into the building. The solar protective glazing is related to the glazing thermal transmittance coefficient (g-value). The g-value determines the amount of energy that will be delivery by the glazing element, being low values more appropriate for hot regions [26].

Figure 3 roughly indicates the optimal U-value for the opaque elements of the building fabric for the Brazilian regions. According to the Passivhaus study [31], the north region presents the highest needed for low U-values (about 0.10–0.15 $W/m^2 \cdot K$), in other words, it requires a more insulated envelope due to the high temperatures that are found in those areas. The south and southeast regions, on the other hand, seem to be easier managed with higher recommended U-values, between 0.3 W/m^2·K and 0.4 W/m^2·K.

Figure 2. Cost-optimal glazing with consideration of heating and cooling. Source: created by the authors based on [31].

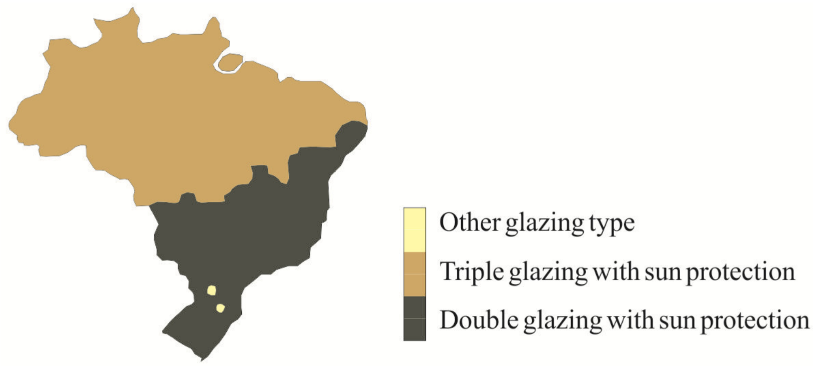
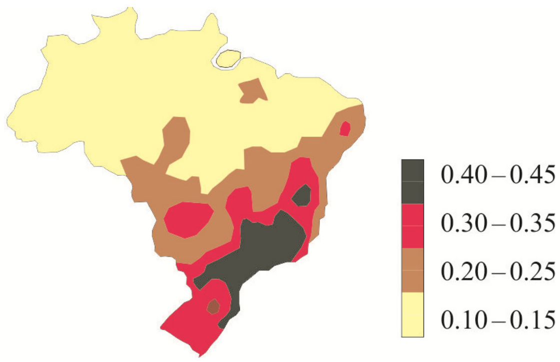


Figure 3. Cost-optimal U-value for the opaque elements of the building fabric with consideration of heating and cooling. Source: created by the authors based on [31].



Comparing these Passivhaus recommended U-values with those proposed by the RTQ-R label, it is possible to identify a significant difference (Table 1). For instance, in terms of the North region of the country, the values adopted by the RTQ-R label are more permissive than those suggested by the Passivhaus study [31]. The RTQ-R label wall U-value requirement for the Brazilian bioclimatic zones ZB7 and ZB8, which correspond to the north region of Brazil, is equal to 2.5 W/m^2·K for absorptance equal to or less than 0.6 and 3.7 W/m^2·K for absorptance more than 0.6. It represents a U-value at least 17 times bigger than the value proposed by the Passivhaus standard. For the roof, the values adopted by the RTQ-R label continues to be very permissive, with a U-value of 2.3 W/m^2·K for absorptance equal to or less than 0.4 and a U-value of 1.5 W/m^2·K for absorptance more than 0.4. In this case, the U-values proposed by the RTQ-R label are at least 10 times bigger than the Passivhaus standard.

Taking the south and the southeast region, the Passivhaus study suggests a U-value variation from 0.20 W/m^2·K to 0.45 W/m^2·K for these areas. In these areas are located the vast majority of the climatic zones, from ZB1 to ZB6. The values recommended by the RTQ-R label vary from 2.5 W/m^2·K to 3.7 W/m^2·K for the walls and 1.5 W/m^2·K to 2.3 W/m^2·K for the roof. As shown, in these areas the U-values recommended by the RTQ-R label are still far from those suggested by the Passivhaus standard.

The use of reflective opaque elements (low absorptance) in warmer regions is highly recommended by both the Passivhaus standards and the RTQ-R label since it reduces the absorption of radiant heat by the surfaces of the building envelope. The use of these reflective opaque elements receives major attention on hotter Brazilian climates zones. According to Table 1, the RTQ-R label allows an increase of the U-value since the absorptance coefficient is smaller than 0.6 or 0.4, depending on the climate zone that the building is designed to. This requirement is not considered to the climatic zones ZB1 and ZB2, where the solar radiation is lower compared with other climatic zones.

Table 1. Summary of the requirements proposed by the Passivhaus standard and the RTQ-R label.

Requirement	Passivhaus Standard	RTQ-R label
Nature of standard	Indoor thermal comfort with minimum energy input	Building Energy saving
Primary energy demand	≤120 $kW \cdot h/m^2 \cdot a$	There are no requirements because the standard encourages bioclimatic strategies.
Heating or Cooling demand	≤15 $kW \cdot h/m^2 \cdot a$	
Heating or Cooling load	≤ 10W/m^2	
Airtightness	≤0.6 air changes at 50 Pa	There is no requirement because it adopts natural ventilation.
U-value wall	≤0.15 $W/m^2 \cdot K$	≤2.5 $W/m^2 \cdot K$ for ZB1-ZB2; ≤3.7 $W/m^2 \cdot K$ when absorptance (α) ≤ 0.6 or ≤ 2.5 $W/m^2 \cdot K$ when α > 0.6 for ZB3-ZB8
U-value roof	≤0.15 $W/m^2 \cdot K$	≤2.3 $W/m^2 \cdot K$ for ZB1-ZB2; ≤2.3 $W/m^2 \cdot K$ when α ≤ 0.6 or ≤ 1.5 $W/m^2 \cdot K$ when >0.6 for ZB3-ZB6; ≤2.3 $W/m^2 \cdot K$ when α ≤ 0.4 or ≤ 1.5 $W/m^2 \cdot K$ when >0.4 for ZB7-ZB8
U-value glazing	≤0.80 $W/m^2 \cdot K$	There is no requirement.
Ventilation system	Mechanical ventilation system	Natural ventilation
Windows	Glazing area: 20% of floor area south-oriented and 5% of floor north-oriented for energy balance	Opening area: ≥5% of floor area for ZB7, ≥8% of floor area for ZB1-ZB6; ≥10% of floor area for ZB8
Method of analysis	Energy balance method	Simulation or prescriptive method
Software	Passivhaus Planning Package (PHPP); it is based on steady state calculations.	It has to comply with ASHARE Standard 140 (2007); it is based on dynamic building simulations.
Comfort temperature	20 °C for winter; 25 °C for summer and 26 °C ≤60% RH for summer	26 °C for summer

5.4. Airtightness and Ventilation

As aforementioned, the Passivhaus standard adopts a mechanical ventilation system with heat recovery. In this system the incoming air is preheated by the extracted air through a heat exchanger without mixing the incoming and the extracted air [26]. For an efficient operation of this system, a very airtight building envelope is required; the functioning of the system usually operates with an air leakage between 0.3 and 0.4 ach at 50 Pa [26] and it must not exceed 0.6 ach at 50 Pa. The advantages of a very tight fabric are related with the preservation of the building fabric by avoiding the entry of humidity into the building and also with the reduction of heat losses or gains by the fabric (depending on the external climate), which normally takes place due to the fabric gaps [26].

In the Passivhaus standard, the windows can be opened but they do not have to be opened for ventilation (although natural ventilation may be used when appropriate). The main purpose here is to achieve a better building energy balance through the glazing areas of the windows. For instance, the Passivhaus suggests the adoption of 20% of floor area for south-oriented glazing and 5% of floor area for north-oriented glazing (north hemisphere) [30]. This recommendation allows maximizing solar heat gain through the south glazing and minimizing heat loss through the north glazing. This requirement has a strong effect of reducing heating load and heating demand during the winter period.

Whilst windows are not necessarily used for ventilation in the Passivhaus standard, the RTQ-R label strongly requires their use for ventilation purposes. The RTQ-R label recommends the opening areas for ventilation to be between 5% and 10% of the floor area, varying accordingly with the Brazilian bioclimatic zone where the building is located [19]. Nonetheless, in the locations where the minimum average monthly temperature is lower than 20 °C, the windows should allow to be closed during the heating period [19]. In Brazil, there is an extensive use of natural ventilation and the main purpose of the windows is for ventilation. The glazing areas are recommended predominantly by the municipalities' standards (building codes) for natural lighting purpose and the opening areas are regulated by building codes and national standards for ventilation purpose. Furthermore, in Brazil, mechanical ventilation systems are not commonly used in dwellings and there are no airtightness requirements since natural ventilation is vastly adopted [35].

5.5. Simulation Software and Comfort Criterion

The simulation software used by the Passivhaus standard differs from that adopted by the RTQ-R label. The Passivhaus standard requires the use of the Passive House Planning Package (PHPP), an excel-based planning tool, which takes use of steady state calculations. The RTQ-R label does not stipulate any specific building simulation software but it requires that the software fulfills the requisites of the ASHARE Standard 140 [36] and also that dynamic building simulations should be conducted for both naturally and conditionally ventilated building envelopes [19].

The Passivhaus standard comfort temperature threshold is assumed to be 20 °C for the cold season and 25 °C for the hot season [28]. Comfort temperature threshold at 26 °C was considered by [31], when low levels of humidity are found (not exceeding 60% of relative humidity). The Passivhaus standard establishes that if the frequency of annual temperatures is exceeded in 10% the temperature threshold of 25 °C, additional design strategies should be provided (*i.e.*, shading), otherwise an overheating will be faced by the building occupants. The RTQ-R label adopts similar comfort criteria with a maximum temperature threshold of 26 °C [19]. Instead of adaptive temperatures, a temperature of 26 °C was set by the RTQ-R label because this parameter can easily demonstrate the difference between solutions performances in case of adopting the HVAC systems [20].

Table 1 comparatively summarized the requirements proposed by the Passivhaus standard and the RTQ-R label.

6. Conclusions

This review paper presented a comparative study of two different voluntary standards designed to improve building fabric performance. The first standard, Brazilian Energy Labelling System for residential buildings (RTQ-R) was launched in Brazil in 2010 and prescribes building fabric standards and hot water systems. The other standard, The Passivhaus standard, was developed based on overall building performance and prescribes maximum use of energy, which can be achieve by following proposed minimum levels of building envelope standards.

The variation between the standards was explored, with regard to their aims, criteria, evaluating method and simulation software. It has been shown that each standard has its advantages and limitations, and that they have different focuses. It was identified, for example, that the RTQ-R label focuses on energy saving (primarily electricity) whereas the Passivhaus standard targets at lower energy consumption overall and higher indoor thermal comfort. Another important observation was the different use of ventilation and, consequently, the differences of airtightness requirements proposed by each standard. The findings of this work suggest that further research is needed to evaluate the benefits of the Passivhaus approach in the Brazilian context. The effectiveness of each of the strategies listed in the Brazilian climates and cultural context, including high levels of insulation and low levels of air permeability will be subject of further studies done by the authors.

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Author Contributions

The different expertise of each author of this paper has equally contributed to its development. Renata Tubelo has brought expertise on the subject of housing and energy use in the context of Brazil. Lucelia Rodrigues has brought expertise on the subject of low-energy housing, building codes/standards and energy ratings. Mark Gillott has brought expertise in sustainable building design and Passivhaus.

Conflicts of Interest

The authors declare no conflict of interest.

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