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COMPARATIVE ANALYSIS OF THERMAL PERFORMANCE STANDARDS FOR BUILDINGS BETWEEN BRAZIL AND THE UNITED KINGDOM

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Monografia de conclusão de curso para obtenção do grau de Engenheiro Civil na Universidade Federal de Ouro Preto defendida e aprovada em 19 de Dezembro de 2018 como parte dos requisitos para a obtenção do Grau de Engenheiro Civil.

Área de concentração: Desempenho Térmico de Edificações.

Orientador: Prof.ª. M.Sc. Júlia Castro Mendes - UFOP

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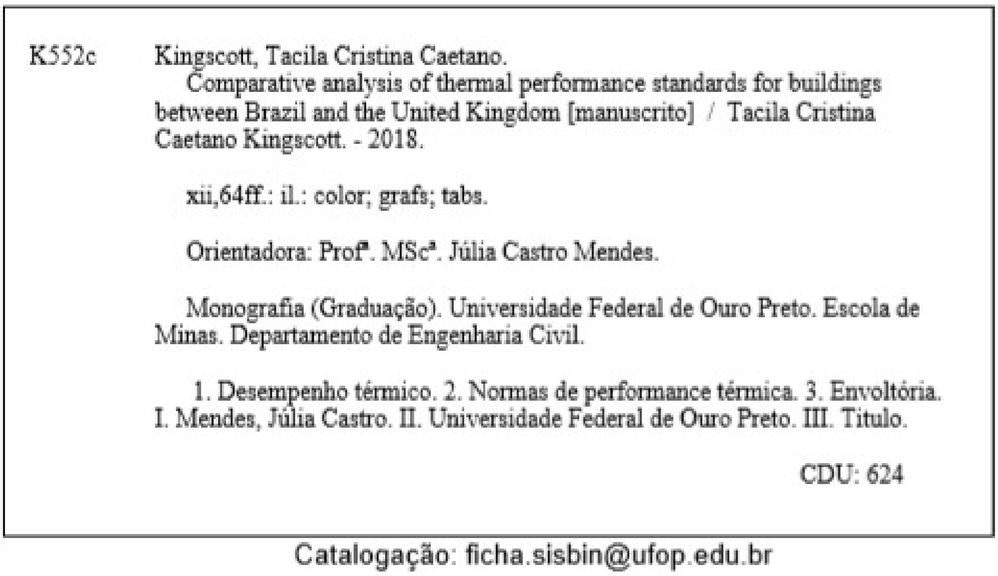

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RESUMO

As deficiências no desempenho térmico de edifícios podem resultar em uma alta demanda por eletricidade, uma vez que os equipamentos de aquecimento, resfriamento e ventilação são usados para remediar o desconforto térmico. O uso dessas estratégias mecânicas também contribui para altas taxas de emissões de CO_2. Por esses motivos, a eficiência térmica dos edifícios é uma preocupação constante para países em crescente desenvolvimento urbano, como o Brasil. Vale ressaltar que parte da população não possui recursos financeiros para manter sistemas de ar condicionado regularmente e, portanto, está exposta às más condições ambientais dentro de suas habitações, o que pode levar ao comprometimento da saúde e da produtividade. Neste sentido, as normas de construção desempenham um papel relevante na garantia do desempenho térmico dos edifícios. As principais normas brasileiras de desempenho térmico foram publicadas em 2005 e 2013 e, portanto, são recentes quando comparadas às de outros países, como o Reino Unido, cujas normas se originaram em 1936. Além disso, sabe-se, cada vez mais, que as normas brasileiras necessitam de melhorias e revisões. O presente trabalho analisa as diferenças entre as normas e as políticas de desempenho térmico do Brasil e do Reino Unido para avaliar como essas políticas afetam a qualidade dos edifícios, levando em consideração os climas de cada país. Neste estudo, a preocupação inicial se baseou na escolha de parâmetros relevantes para a realização das comparações. Ressalta-se que as normas de desempenho térmico brasileiras, quando comparadas às do Reino Unido, estão desatualizadas e não são suficientemente abrangentes para incluir diferentes tipos e fases de construções. Além disso, as simulações e parâmetros de desempenho térmico são fortemente simplificados nas normas brasileiras, em comparação com as do Reino Unido, o que pode resultar em vulnerabilidades de projeto. Esses resultados reforçam a importância da atualização frequente das normas, para solucionar ambiguidades e incluir novos aspectos. Adaptar as estratégias de outros países com políticas promissoras pode melhorar significativamente o conforto térmico e o desempenho energético global dos edifícios.

Palavras-chaves: Desempenho térmico; Normas de performance térmica; Envoltória.

ABSTRACT

Deficiencies in the thermal performance of buildings can result in a high demand for electricity, since heating, cooling and ventilation equipment are used to remedy the effects of thermal discomfort. The use of these mechanical strategies also contributes to high rates of CO_2 emissions. For these reasons, the thermal efficiency of buildings is a consistent concern for countries with increasing urban development, such as Brazil. It is worth mentioning that part of the population does not have the financial resources to maintain air conditioning systems regularly and, therefore, they are exposed to poor environmental conditions within their dwellings, which can lead to the compromise of health and productivity. In this sense, the requirements of building standards play a relevant role in ensuring the thermal performance of buildings. Brazilian main thermal performance standards were published in 2005 and 2013, and thus are recent when compared to those of other countries, such as the United Kingdom (UK), whose standards date further back from 1936. Furthermore, Brazilian standards knowingly require improvements and revisions. Thus, the present work analyses the differences between the standards and the thermal performance policies from Brazil and the UK to evaluate how these policies affect the quality of buildings, taking into account the climates of each country. In this study, the initial concern was based on the choice of relevant parameters for the accomplishment of the comparisons. It is noteworthy that the Brazilian thermal performance standards, when compared to the United Kingdom, are out of date and are not comprehensive enough to include different types of buildings and construction phases. Furthermore, the thermal performance simulations and parameters are oversimplified in the Brazilian standards, in comparison to the UK, which may result in design vulnerabilities. These results reinforce the importance of frequently updating standards to solve ambiguities and to also include new aspects. Adapting the strategies of other countries with promising policies can significantly enhance the thermal comfort and improve global energy performance of buildings.

Keywords: Thermal performance; Thermal performance standards; Envelope.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

LIST OF ABREVIATIONS

ABNT - Brazilian Association of Technical Standards

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers

HVAC – Heating, Ventilation and Air-conditioning

ISO - International Organization for Standardization

LIH – Low - Income Housing

SAP - Standard Assessment Procedure

SBEM - Simplified Building Energy Model

SBS – Sick Building Syndrome

TER - Target CO_2 Emission Rate

TFEE - Target Fabric Energy Efficiency

UHI – Urban Heat Island

UK – The United Kingdom

1 Introduction

From the basic instinct of survival to improving productivity of the workplace, humankind seeks to overcome climatic conditions to achieve both comfort and safety. Due to the intensification of urbanization and the search to improve the quality of the built environment, the importance of the energy efficiency concept in buildings was reinforced. This concept encompasses the ability of a building to provide thermal, visual and acoustic comfort through reduced energy consumption compared to similar buildings in the same environmental conditions (LAMBERTS, DUTRA e PEREIRA, 2012).

In this sense, the need to promote thermal conditioning to living and work spaces has generated a growing demand for energy. Buildings consume 40% of global primary energy and contribute to more than 30% of CO_2 emissions. A large part of this energy is used to enhance thermal comfort in buildings and it is estimated that a systematic approach can result in potential energy savings of 5% to 30% (COSTA, KEANE, *et al.*, 2013).

The building sector is one of the leaders in the total consumption of energy, surpassing the industry and transportation sectors in many developed countries (YANG, YAN e LAM, 2013). Similarly, in Brazil, the residential sector consumes 28.8% of the total energy produced in the national territory (EPE, 2017). This consumption, when used for heating and cooling environments may arise as a consequence of constructive and standardizing deficiencies responsible for the progressive waste of air conditioning in buildings. For this reason, thermal performance in buildings is a relevant issue when it comes to energy policies around the world for both developed and developing countries.

Not only the energy efficiency of the building is improved, adequate thermal performance can have significant impacts on the user’s health and productivity. Therefore, it is necessary to understand how the relationship between man and the environment can be utilised, in the sense of thermal comfort, to positively influence these two aspects (IIDA, 2005). Working environments such as offices in both the United Kingdom (UK) and Brazil need to meet temperature requirements as “Health and Safety at Work etc. Act 1974” and “DECRETO-LEI Nº 6.514, art.178 (1977)” respectively outline, to preserve the well-being of the workforce. According to SAUNDERS (2002), the local conditions, construction, design and maintenance have an effect on the health of the occupants not only in offices, but also in schools, hospitals, shopping malls and even private residences. When the buildings are not well designed, the deficiencies can lead to malaise due to poor construction conditions. Malaise, in addition to mucosal, skin, and general symptoms are associated to “Sick Building Syndrome” (SBS), described as: “an excessive number of subjective complaints by occupants of a building” (STOLWIJK, 1991).

Based on the above considerations, the standards of thermal performance of buildings have brought economic benefits, longevity and the rationalization of resources. In addition to providing techniques for constructive processes, versatile enough to accommodate local climate, they provide definitions, classify parameters, and set guidelines to condition an efficient and favourable thermal environment (MARKOV, 2002). In this sense, up-to-date standards guide the construction industry to prioritize more sustainable solutions. On the other hand, despite their undeniable importance, outdated standards can lead to inconsistent constructive processes. For example, the Brazilian Standard NBR 15575: Residential buildings — Performance and NBR 15220-3: Brazilian bioclimatic zones and building guidelines for low-cost houses, have been criticized by some authors who consider them too simplified and not suitable for realistic applications (BOGO, 2016).

Currently, challenges related to constructive shortcomings stem from the current standards in practice and their lack of versatility. At the same time, climatic conditions have undergone changes and peaks over the years. Thus, there is a need to compare, adopt and adapt the thermal performance policies from countries with successful implementations.

1.1 Objectives

This study aims to compare the performance standards of buildings between Brazil and the United Kingdom in terms of thermal performance quality.

1.1.1 Specific Objectives

- Analyse the differences in the thermal performance policies of buildings between Brazil and the United Kingdom;
- Evaluate how the differences in thermal performance policies affect the quality of buildings, taking into account their respective climates;
- Outline the challenges faced by Brazil and what can be learned from the solutions adopted by other countries.

2 LITERATURE REVIEW

2.1 Thermal Performance of Buildings

According to GONÇALVES, VANDERLEY, *et al* (2003), the meaning of the word "performance" is defined as the behaviour of a product when in execution. The product must have specific properties to fulfil its proposed function when subjected to actions during its service life, called "exposure conditions". Therefore, in order to evaluate the performance of a building it is necessary to define, in quantitative and qualitative ways, the conceptual purpose of the building, and parameters to evaluate the quality once the exposure conditions have been met.

There is a distinction between thermal performance and thermal behaviour. The thermal behaviour is characterized by the physical reaction presented by the building when exposed to the external climate and the effects of the internal functioning elements (LAMBERTS, GHISI, *et al.*, 2010). In this sense, it considers the heat generated due to the occupation of people and equipment inside. In order to identify the different physical reactions of the building, it is necessary to observe aspects such as the change of temperature and humidity of the internal air, or even how the heat is transmitted through the housing structures such as the walls and coatings. On the other hand, thermal performance is characterized by the comparison between the aspects previously stated and a predefined set of parameters for each building type to attend the expectations of the users (LAMBERTS, GHISI, *et al.*, 2010).

To evaluate the thermal performance of a building, procedures can be adopted at the design stage or post construction. In a study coordinated by BARBOSA, CARBONARI, *et al.* (2003), related to the thermal performance of residential single-family buildings, it is stated that a computer simulation of the construction system is a reliable method. In this process, the results are analysed according to the limits or parameters of thermal comfort adjusted for the local population (demographics). The total annual hours in which the internal simulated temperatures are above the temperature limits of the comfort zone are an example. Another method of thermal performance is the evaluation by prescription. In this method, limits are established for thermophysical characteristics of the building materials; in addition, there are recommendations for ventilation and shading design in order to adapt the project to the local climate (FOLLE, MARTINS, *et al.*, 2012).

Residential buildings are usually less occupied than commercial ones; therefore, the internal heat generation coming from machines, artificial lighting and people is also lower. Thus, the thermal performance of a residential building is mainly determined by the heat gains through external surfaces and conditions of exposure to sunshine and ventilation (LAMBERTS, GHISI, *et al.*, 2010). In this sense, the patterns of occupancy and use will interfere in the thermal behaviour of a residence. The way users manipulate ventilation and insolation devices impacts building gains and losses of heat.

2.2 Thermal Comfort

The internal temperature of the human body tends to remain constant, independently of the external climatic conditions. This characteristic is known as Homeothermy. Through the metabolism, the organism transforms the food into energy, generating the internal heat of the body. However, thermal changes can occur between the body and the environment through conduction, convection, radiation, evaporation and respiration (Figure 1), which can result in changes in body temperature (LAMBERTS, DUTRA e PEREIRA, 2012).

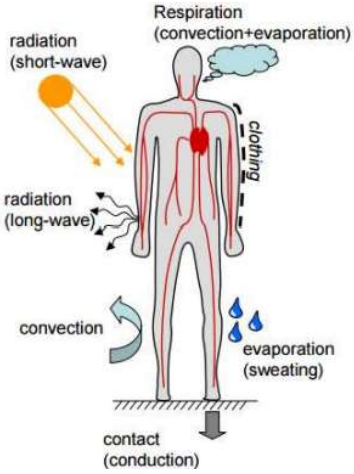


Figure 1 – Thermal Exchange between the human body and the environment (Paulke, S.,2008).

In this sense, the thermal comfort represents the mental state that expresses satisfaction with the surrounding environment (ASHRAE, 2005). A feeling of dissatisfaction comes from the discomfort caused by the lack of thermal balance between the body and the environment. Therefore, thermal comfort methodologies aim to study, quantify and mitigate this issue. Due to the physiological and psychological differences between humans, the task of satisfying the majority of people in the same space can be difficult to achieve. However, humans, all biologically similar, have adapted to radically different climates through the use of clothing, technologies and architecture. (LAMBERTS, DUTRA e PEREIRA, 2012).

In the scope of construction, planning is essential in order for the budget to satisfy the social and sustainable dimensions to obtain comfort. The level of environmental comfort has a direct correlation with the economic dimensions of the project, as there is a cost associated to providing heating, ventilation and air-conditioning (HVAC) systems. As well as the cost implications, the environmental impacts should also be considered due to the energy consumption of those artificial systems. Achieving environmental efficiency by reducing water and energy consumptions is not enough if the interior space fails to provide comfort; however, similarly, excessive energy expenditure to solve the lack of comfort is also not acceptable (REVISTA TÉCHNE, 2010). Balancing the economic and environmental elements of a project is key to achieve efficacy in cost, carbon footprint and thermal comfort.

2.2.1 History

According to SCHMID (2005), the term comfort began to be applied to buildings in the mid-nineteenth century, initially in Europe. However, during the Modernism of the early twentieth century, the notion of comfort was devalued and considered unfit for the vogue aesthetic (of engineering and progress). Thus, houses of the period (Figure 2) incorporated the coldness of modernism with white walls and tubular steel furniture. Le Corbusier, architect and important mentor of the movement, propagated the objectivism of the concept of home as a "living machine", refusing sentimentality.

a) **b)**

Figure 2 – a) House located at Av. XV de Novembro, Maringá, Paraná - Brazil. Engineer: Luty Kasprowicz, 1966, depicting the architecture of the first half of the 20th century (REGO e DELMONICO, 2003); b) Modernist House: José Ferreira Penteado Residence, 1934 (ZAKIA, 2005).

In the early 70's, the energy requirements for buildings began to be questioned in the face of the 1973 oil crisis. During the time of Modernism, buildings concepts did not prioritise energy-efficiency and therefore failed to accommodate specificities such as varied climates, cultures and landscapes. In this scenario, concepts such as bioclimatic architecture, passive architecture and sustainable architecture began to emerge. These broader environmental concepts were then taken into consideration during the architectural design phase and recognised as fundamental elements of a building (SCHMID, 2005).

Currently, the concept of thermal comfort has become indispensable in the expansion of architectural projects. Unlike the isolated way initially developed by specialists, it is now compatible for varied problems and circumstances. This systematic and holistic approach is also a result of indirect advances, such as environmental movements, stablished consumer rights, and general demand for improved quality (KOWALTOWSKI, LABAKI, *et al.*, 1998).

2.2.2 Importance for Health and Productivity

According to LAMBERTS, DUTRA e PEREIRA (2012), the internal temperature of the organism is on average 37°C and the heat gain or loss can influence this temperature, cause health issues, and even death. Therefore, the body's natural thermoregulatory mechanisms exist to keep the internal body temperature constant.

Thermal environments are responsible for the human psychological responses to thermal sensations associated with cold or heat. In environments with low rates of woodlands and high density of urbanization, factors such as the storage and exchange of heat by building materials, alongside the decreased ventilation and evapotranspiration, create an urban heat island (UHI) (BIAS, BAPTISTA e LOMBARDO, 2003). The UHI effect results in a higher temperature than that of the surrounding areas, as seen in Figure 3. Natural seasonal heatwaves have a drastic impact on urban populations often causing overheating. It has also been noted that climate change has exacerbated these effects (SOLECKI, ROSENZWEIG, *et al.*, 2004).

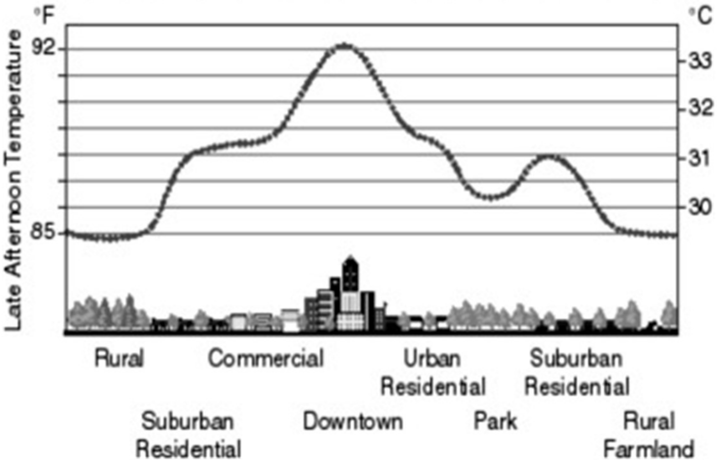


Figure 3 – Urban-Heat Island profile (SOLECKI, ROSENZWEIG, *et al.*, 2004)

Among the consequences of the UHI, an increased energy consumption due to the cooling demand stands out, especially in the summer. Knowing that, in most of the world, energy is produced from fossil fuel sources, polluting gases such as CO_2 are emitted in larger quantities in this period (BIAS, BAPTISTA e LOMBARDO, 2003).

In the United Kingdom, a family characterized as a "fuel poverty family" is defined as one that requires fuel costs above the average, mainly for the level of adequate thermal conditions in their homes. Once the threshold has been reached, their residual income would be below the official poverty line (BEIS, 2017). Low income and thermally inefficient houses are the factors which contribute to fuel poverty. To highlight the impact of fuel poverty (Figure 4), in 2015, an estimation of 2.50 million households are categorised as fuel poverty, this represents 11% of UK households which, after paying for fuel, are left with insufficient income

Roughly 4 million households in the UK find it financial difficult or often impossible to keep a warm home. Social isolation can lead to depression and mental health problems as well as coronary heart disease. This could be correlated to the person saving money for fuel and also the unwillingness to socialize in a cold home (PRESS, 2003).

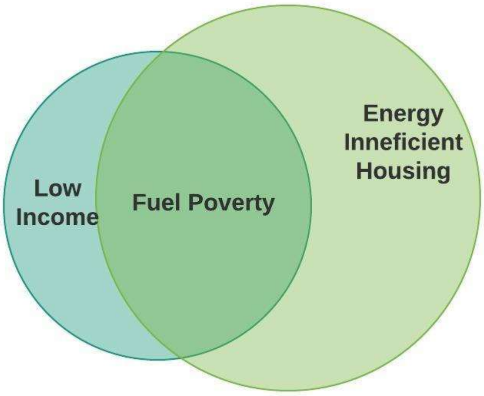


Figure 4 - The relationship between fuel poverty, energy inefficiency and low income (Adapted from BAKER, 2001 based on source material from NRFC, 2000).

In this context, the guide produced by the National Heart Forum (2003), reports on the effects of thermally inefficient homes on human health. The handbook describes that, on average, more than 40,000 people die in the UK as a result of low temperatures during the winter (between December and March). The causes of these deaths are cardiovascular diseases, responsible for more than half of the total deaths, and respiratory diseases, corresponding to one third. However, this level of mortality is not observed in countries with more severe winters than the UK, such as Finland and Russia, since these countries are more readily prepared to deal with harsh climates. This excess mortality could be largely countered by appropriate thermal performance in buildings.

Adequate home heating, insulation, and ventilation systems ensure a combination of favourable temperatures and humidity levels. Therefore, it can also enhance the immune system from diseases, and even promote a rapid recovery in the event of this occurring (PRESS, 2003). It is observed that living in temperatures constantly below 18°C may result in a higher propensity for respiratory diseases and the risk of cardiovascular diseases (PRESS, 2003).

The feeling of comfort is not always noticed when the climate inside a room is already pleasant. However, as soon as the level of comfort fades, some people may become dissatisfied. Overheating can lead to fatigue, signs of drowsiness and a reduction in physical performance. Overcooling can reduce concentration and alertness in activities which require mental application (KROEMER e GRANDEJEAN, 2005). In Table 1, it is possible to observe the effects of the variation in temperatures within a living space to the human health and the sensation of local comfort.

Table 1 - The effect on comfort and health of exposure to varying living room temperatures

Indoor Temperature	**Effect**
21ºC	Comfortable temperature for all, including older people, in living rooms.
18 ºC	Minimum temperature with no health risk, although older and sedentary people may feel cold.
Under 16 ºC	Resistance to respiratory diseases may be diminished.
9-12 ºC	Exposure to temperatures between 9ºC and 12ºC for more than two hours causes core body temperature to drop, blood pressure to rise and increased risk of cardiovascular disease.
5 ºC	Significant increase in the risk of hypothermia.

Adapted from **(PRESS, 2003)** based on source material from **(COLLINS, 1986)**

People who are more vulnerable to the risks of cold and humid buildings are those who spend longer periods of time inside and those who are naturally more susceptible to cold illnesses: the elderly, children, people with disabilities, and people with long-duration illnesses. A study carried out in Glasgow demonstrates that asthmatic people attending clinics tend to live in dwellings with evidence of 2 to 3 times higher relative humidity than other people of the same age and sex living in the same region of the city. The severity of mould and moisture present in a home is significantly related to the severity of asthma (WILLIAMSON, MARTIN, *et al.*, 1997).

Likewise, human productivity is also affected by the thermal comfort of buildings. A study conducted by SOMERVILLE, MACKENZIE, *et al.*, (2000) showed that energy improvements in homes can lead to a decrease in the rate of school failure of asthmatic children or those with constant respiratory infections.

2.3 Buildings and Thermal Comfort

Considering the ideal conditions of a project for tropical climates such as Brazil, buildings have a greater need to provide ventilation and to mitigate the effects of heat gains from solar radiation. Since the need for heating is low, cooling strategies are fundamental to architectural projects. These strategies can occur either actively or passively.

According to BITTENCOURT e CÂNDIDO (2005), there are three ways to provide this cooling: active, hybrid and passive strategies. The first is characterized by the use of technologies that require energy, such as air conditioning. The second method includes energy-consuming systems, but only in selected parts of the building, and allowing other parts to be maintained with passive cooling. The passive cooling, in turn, comprises sustainable strategies for cooling buildings by natural means. It is performed by controlling the heat exchange with the environment to obtain a lower indoors temperature, and a low energy consumption (GIVONI, 1982). For this situation, the natural ventilation, the building envelope, as well as the permeability of the building to the wind represent significant characteristics.

2.3.1 Active Strategies

The active strategies for thermal comfort are those that depend on an external device, that is, a mechanical or artificial aid to promote heat transferences from the building. The advantage of using this type of system when compared to other strategies is the greater and more dynamic control of the heat flow. On the other hand, as a disadvantage, it requires electricity, which will result in an increase in energy consumption, costs and contribution to CO_2 emissions. This is valid for heating or cooling demands.

Some considerations such as the local climate and the functionality of the building require the use of HVAC systems. In this sense, private and public buildings can expect the use of active climate control, since productivity is an implicit factor (LAMBERTS, DUTRA e PEREIRA, 2012).

Mechanical ventilation systems are divided into extractor fans and fans. Extractor fans are generally used in environments where there is a possible source of air pollutant, such as kitchens, bathrooms, laboratories, among others; while fans are used to promote fresh air and air circulation in general areas. Extractor devices blow hot or contaminated air out of the room through a negative pressure. Regarding fans, there are two types: fixed and portable. The sensation of thermal comfort felt by the person is a consequence of the convection created by the fan that results in the evaporation of sweat, and the consequent withdrawal of heat from the skin (LAMBERTS, DUTRA e PEREIRA, 2012).

In turn, the refrigeration systems are those responsible for promoting cooling and dehumidification of the environments. According to EPE (2017), between 2005 and 2016, in Brazil, the possession of air conditioning equipment in residences increased by 10% per year. The same study showed that, in 2005, 7% of the total consumption of electricity was dedicated to the use of air conditioners and in 2016 this rate increased to 13%, due to the higher demand for air conditioning equipment.

The simplest forms of interior heating systems are: local heating or direct heating. The sources of energy used for these systems are: electricity, gas, oil and/or solid fuels. The electric heating is the most widespread because it presents simplicity of installation and operability, low cost for the transport of energy and does not require combustion (LAMBERTS, DUTRA e PEREIRA, 2012). Electric Heaters work by sequentially heating portions of the air around the apparatus by transferring electricity into heat. The way the heating occurs and how the heat exchanges with the environment defines the differences between types of heaters.

Central Heating systems generally use solid fuels or renewable energy sources and replace individual portable appliances. In this type of system, water or air is heated (in boilers or furnaces), in a place other than the rooms where the heating is intended. Subsequently, the fluid is distributed through pipes and passes through radiators located inside the rooms which emit heat by radiation and convection (LAMBERTS, DUTRA e PEREIRA, 2012). As stated in a study performed by BALARAS, DROUTSA, et al., (2005) using estimates made in 193 audited buildings from five European countries (Denmark, France, Hellas, Poland and Switzerland), central heating systems are more energy efficient to meet the heating demand of buildings, since individual heating systems have a higher energy consumption.

Other artificial heating systems such as radiant floor heating systems and baseboard heaters are also a way of providing thermal comfort to the living or working environment. The floor heating systems can distribute heat through electricity or through hot water pipes, where there is heat irradiation on the floor from underneath up through convection. In baseboard heaters, the system power can be electric, gas or solar. In this type of system, it is necessary to do prior planning to avoid heat losses in the pipes (LAMBERTS, DUTRA e PEREIRA, 2012).

2.3.2 Passive Strategies

Contrary to active measures, passive strategies utilise natural resources to provide a suitable internal temperature in buildings without the use of energy-consuming systems. The option for this type of strategy is advantageous as it promotes the reduction of the peak heating/cooling load in the buildings resulting in little or no need for mechanical conditioning, in periods that would typically require it (KAMAL, 2012).

This type of strategy works to prevent indoor heat gain, modulation of heat gains and through natural cooling and the dissipation of heat from within the building. Firstly, in terms of design, care is required with landscaping, planning, interior furnishings, constructive materials, sun shading and thermal insulation. Secondly, the modification of heat gains is linked to the heat storage capacity of a building, which must be planned so that there is no excessive heat oscillation, and thus achieving improvements in thermal comfort. Finally, heat dissipation from the occupation and the internal emissions can be promoted via radiative, evaporative, or convective transfer or by ground cooling (LIMB, 1998).

For buildings to promote thermal conditioning passively it is important to follow the bioclimatic design. This design methodology considers and incorporates the local climate when applying constructive techniques and architectural elements, with the purpose of providing a satisfactory degree of thermal comfort to the environment, whilst saving energy (BITTENCOURT e CÂNDIDO, 2005). The bioclimatic design considers the following principles (CRES, 2018):

- Heat insulation of the buildings using appropriate techniques such as suitable external enveloping;
- The use of solar energy for heating and daylighting, all year long;
- Protection from summer sun, primarily by shading but also through the use of reflective colours and surfaces;
- Removal of the summer accumulated heat by natural means, such as passive cooling systems and techniques;
- Improvements such as increasing the free flow of air inside spaces and the heat or cool storage in walls;
- Ensuring insolation combined with solar control for daylighting inside the buildings;
- Improvement of the ecosystem around the buildings through the bioclimatic design of external spaces.

As reported by LAMBERTS, DUTRA e PEREIRA (2012), the building materials strongly influence the thermal performance of a construction. The comfort conditions can be improved by avoiding excessive heat loss or gain through envelope insulation, sun shielding on walls, roof windows, as well as the type of tiles and glazing. To work together with the local climate, a thorough consideration of the thermal conductivity of the building materials is required.

2.3.2.1 Examples of passive strategies

a) Thermal Insulation

According to MADHUMATHI, RADHAKRISHNAN e SHANTHIPRIYA (2014), the building envelope behaves like a thermal barrier and determines the amount of energy needed to promote comfort to an internal environment whilst taking the external environment into consideration. The protection of the roof, the sunlit walls and the windows that receive direct exposure to sun light are fundamental elements to control the solar heat gains. The principle of correct thermal insulation applies to both opaque surfaces such as walls, floors and roofs, as well as to transparent surfaces such as windows. Thus, as can be seen in Figure 5, roofs and walls are considerable contributors to the indoor heat transfer of buildings.

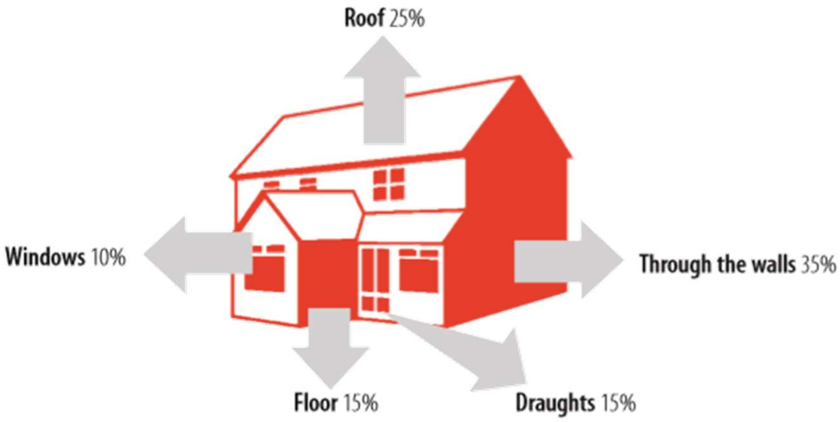


Figure 5 - Heat exchanges within a building (NEA, 2001).

Heat flow occurs when a temperature difference between the exterior and the interior is present. This flow happens from the warmer surface to the cooler surface. For this reason, in the summer, external temperatures tend to be higher and therefore will result in heat exchanges with the internal environment (LAMBERTS, DUTRA e PEREIRA, 2012). Thus, the ability to retain heat is associated with the materials forming the envelope, as well as with the thermal inertia of these compositions.

Thermal inertia is a characteristic of the material directly proportional to the heat retained, that is, the greater the thermal inertia of a material, the more heat it retains. An example is the use of the thermal inertia of the envelope components, such as roofs, to accumulate heat from the sun during the daytime, store it and return it overnight inside the building (LAMBERTS, DUTRA e PEREIRA, 2012). For dwellings in moderate and cold climates, where the use of active strategies is not usually needed, there's cases where thermal inertia is disadvantageous for intermittently heating buildings. However, for the most part, high mass buildings outperform the low mass variants with both lower heating and cooling demand (SANTAMOURIS, SYNNEFA e KARLESSI, 2001).

The microstructure and density of the materials used to compose the envelope will define the amount of heat stored by it, known as thermal mass. Heavier components take longer to heat up and if the specific heat capacity is high, consequently these materials can store a greater amount of heat (PFUNDSTEIN, GELLERT, *et al.*, 2008). However, some materials such as cork, styrofoam, glass wool and cellular concrete are thermal insulation with low density (porous). The potential for heat transfer reduction pertaining to these materials is due to the air entrapped in the pores. Thus, to reduce the heat flux of an envelope, the insertion of an air chamber in its interior (through the use of insulating materials) is an alternative (LAMBERTS, DUTRA e PEREIRA, 2012).

In transparent surfaces, such as windows, skylights, among others, thermal transfer may occur through conduction, convection and radiation. The dimensions of the opening will influence the amount of heat exchanged with the environment (LAMBERTS, DUTRA e PEREIRA, 2012). Not only the dimensions, but the different types of glass have different characteristics of absorption, reflection and transmission of radiation from the sun. Similar to how the porous insulation materials above capitalise on the low conductivity of air, double glazing windows also utilise this method. The thermal conductivity of double-glazed air-filled windows is approximately 40% less than single glazed windows (PILKINGTON, 2018) as seen in Table 2:

Table 2 – U values (W/m²K) for windows with wood or PVC-U frames

	Gap between panes		
	6mm	12 mm	≥ 16 mm
Single glazing	4.8		
Double glazing (air filled)	3.1	2.8	2.7
Double glazing (argon filled)	2.9	2.7	2.6

Adapted from (PILKINGTON, 2018).

These values can be further improved by replacing the air between the glazed windows with argon, which has a 33% lower heat conductivity than air (

Table 3). This reduction in heat transfer can result in a lower demand for active heating energy.

Table 3 – Thermal conductivity of common gases

Thermal conductivity in mW m^{-1} K^{-1}						
	100 K	200K	300K	400K	500K	600K
Air	9.5	18.5	26.4	33.5	39.9	46.0
Argon	6.3	12.4	17.7	22.4	26.5	30.3

Adapted from (HUBER e HARVEY, 2011)

Colours associated with external surfaces can also influence the heat absorption of buildings and reduce the surface temperatures of the envelopes. Materials called "cool materials" maintain the lowest surface temperature because they have high solar reflectance and infrared emittance (SANTAMOURIS, SYNNEFA e KARLESSI, 2001). For example, a built-up roof cover with a smooth, black asphalt surface, can have an initial reflectance of 0.04 or 0.80 if coated with a smooth, white surface. In the same way, a single-ply membrane can show an initial reflectance of 0.04 if black, contrasted by 0.20 if grey and even better 0,80 if white (SANTAMOURIS, SYNNEFA e KARLESSI, 2001). According to studies by AKBARI e KONOPACKI, (2005), in 240 regions of the USA, the use of strategies such as the application of cool materials and vegetation cover to mitigate heat islands resulted in an energy reduction for the cooling of buildings (5-18% office buildings, 7-17% commercial buildings).

Optimization of the thermal performance of the roof is obtained through geometry, colour, ventilation levels and thermal mass. Thus, among the requirements for roofing, the following stand out (MADHUMATHI, RADHAKRISHNAN e SHANTHIPRIYA, 2014):

- Low thermal capacity in the prevention against excess of heat accumulation, in the cases that this property is not desirable;
- The resistance to rain penetration, with yet sufficient permeability for moisture flow (absorption and release when necessary);
- Resistance to external agents such as fungi, insects, rodents and even solar radiation;
- Considerable reflectivity for the reduction of thermal load and thermal movements;
- Resistance to temperature and humidity fluctuations;

b) Microclimate and site design

According to CAMUFFO (2014), microclimate refers to the composition of the physical conditions of the environment due to atmospheric variables and exchanges with other bodies, over a period of time sufficiently representative of the conditions generated by artificial and natural factors.

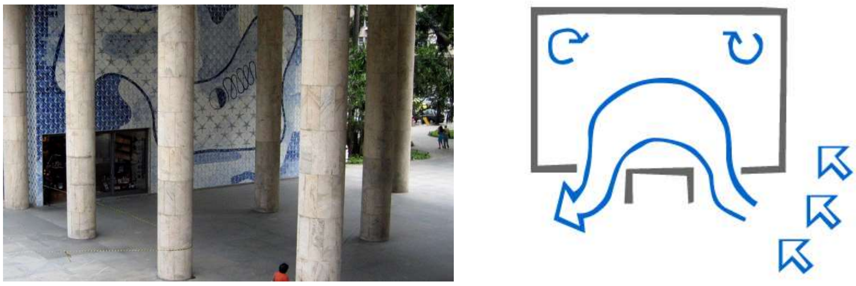
The importance of the study is associated with the possibility of obtaining architectural solutions that support the comfort of the occupants maintaining the concept of energy efficiency, by evaluating the particularities of the environment where the building is inserted. The microclimate incorporates variables such as vegetation, natural composition, topography, location and even other man-made constructions. From the application of this concept, the planning of buildings includes the use of local characteristics to support aspects such as lighting, ventilation and landscaping, sometimes reducing the needs for active measures or incorporating them effectively when necessary.

Modifying the microclimate around buildings can result in a drop in peak cooling and improvements in indoor comfort conditions. In order to make this modification, elements such as appropriate location, landscaping, and terrain layout are essential. A suitable location can bring advantages such as natural sun protection and strategic winds. Specific cooling strategies may exist when considering the local climate and context. Thus, vegetation besides providing natural protection to sunlight, exerts a natural evaporative cooler function (ANTINUCCI, ASIAIN, *et al.*, 1992).

The planning of a city as well as the supporting regulations must incorporate the ideology of a microclimate. Whilst this minimizes building pathologies caused by natural elements such as wind, rain, solar, cold, snow among others, it also mitigates the requirements of active solutions by using the natural environment to support passive ones.

c) Building Layout

The orientation of the building and the beneficial distribution of interior space behaves as regulators of solar radiation avoiding the overheating and exposure to wind and its channelling in and out of the building. Therefore, the choices of building formats can be advantageously exploited to facilitate the heat dissipation. Some examples of constructions managing heat dissipation are: building on *pilotis*, use of wing walls and courtyard forms (Figure 6) (ANTINUCCI, ASIAIN, *et al.*, 1992).



a) **b)**

c)

Figure 6 – a) Construction on *Pilotis* in Rio de Janeiro. (Adapted from CAU/BR, 2018); b) Illustration of how to divert air into homes with Wing Walls (Build, 2018); c) Diagram of different ranges for a Courtyard (Moss, 2014).

In the same way, the zoning of interior rooms - areas with constant thermal needs, can be suggested as a thermal buffering strategy, in an attempt to avoid heat gains or even the transferral of heat. It can be used as a strategy when considering the different types of functions attributed to the building. The building layout can support passive ventilation strategies, for example having an open horizontal plan can encourage cross ventilation - the movement of air in, through and out of the building (LAUREANDO, 2014). Vertical zoning provides the advantage of temperature stratification, since the upper levels tend to be warmer than the lower ones (BROWN and DEKAY, 2001).

As a natural strategy, cross ventilation promotes the cooling of indoor environments by implementing inlets and outlets openings (windows) allowing air to flow through the building and thus removing heat. For sufficient heat dissipation to take place, the number of outlet areas for cross ventilation should be greater than or equal to the number of inlet areas (GRONDZIK, KWOK, *et al.*, 2010).

During the winter, the heat generated within a building is constantly transmitted through exterior surfaces such as walls, windows, roofs, among others. As the relationship between the surface area to volume is directly proportional to heat transfer, the building's shape may be used as a means for reducing the ratio of exposed surface area to internal building volume, thus being able to influence the heat transfer (ISOLANI, 2008). When this ratio is off balance, the energy efficiency of the building may be compromised and artificial heating or cooling may become necessary.

However, it’s important to factor aesthetic preferences, planning permission and constructive costs as this may limit the manipulation of the building shape. For example, in southern Europe, different lengths of multi-storey blocks arranged in rows is a common composition. This arrangement, of low surface to volume ratio, makes it difficult to control aspects such as shape, orientation and location by the designers, and thus can result in overheating (ANTINUCCI, ASIAIN, *et al.*, 1992).

d) Behavioural, occupancy patterns and internal gain control

The heat generated inside the buildings is also related to the aspect of human occupation and machinery. The use of the building (commercial, residential or public) will influence the number of occupants and the energy consumption (LAMBERTS, DUTRA e PEREIRA, 2012).Thus, building management policies that limit the number of people in certain locations can influence the heat gains of a given area. Awareness that involves turning off equipment when not in use or strategies such as window shading can prevent internal overheating. In the same way, the use of energy-efficient equipment contributes to the reduction of internal loads of heat within a given space.

2.3.2.2 Modulation and Heat Dissipation Techniques

Natural heat sinks such as the atmosphere at night, building mass, ground soil, among others can be used for storing and removing heat gains from a building. Modulation and heat dissipation techniques utilize the thermal mass of such heat sinks for natural cooling measures (SANTAMOURIS e ASIMAKOUPOLOS).

As an example of heat dissipation technique, Night Ventilation is a passive cooling technique in which the heat accumulated during the day is relieved at night through the intentional intake of external cold air (naturally or mechanically) (KOLOKOTRONI, WEBB e HAYES, 1997). In this way, the external air cools the internal air and the fabric of the building, slowing the rate at which the internal air will be heated during the day. The aim is to cool the spacing by flushing out hot air through the use of, for example, cross ventilation.

2.3.3 Hybrid Strategies

Hybrid strategies, as the name suggests, are those that include both active and passive solutions for regulating temperatures and providing comfort. This versatile approach caters to different seasonalities using both mechanical and natural tools to achieve the most satisfactory outcome.

Understanding hybrid strategies is crucial when complying with energy efficient schemes and government issued standards and regulations, which try to encourage the application of passive solutions to regulate temperature, whilst reducing energy consumption. An example of this can be seen in the European voluntary standard: Passivhaus. This standard was first developed in Germany, in the late 1980's, with the aim of reducing energy consumption and at the same time contributing to ultra-low energy and zero carbon in different types of buildings (MCLEOD, HOPFE e KWAN, 2013). Moreover, a building does not need to be certified to be a Passive House, however an option for a certification helps to prove the quality of the building and also a more trusting relationship between client and contracted (IPHA, 2018). Overheating issues in Portugal, Italy and even the UK resulted in an investigation to adapt these regulations and find alternative concepts to achieve a satisfactory thermal comfort in different climates (COSTANZO, EVOLA, *et al.*, 2017). The Passivhaus requires heating and cooling energy consumption to be below the threshold of 15 kWh $m^{-2}y^{-1}$. The Passivhaus regulation is widely accepted in colder regions but faces many challenges in warmer climates (COSTANZO, EVOLA, *et al.*, 2017).

An example of the use of hybrid systems can be seen in the study performed by COSTANZO, EVOLA, *et al.,* (2017). The findings of this investigation were applied when refurbishing a block of flats in Sicily, Italy, where the temperature has wide fluctuations from summer to winter. Due to the large surface area of the roof exposed to the environment, heat was lost rapidly during the winter, resulting in higher demand for heating. On the other hand, the horizontal plan also captured large quantities of solar radiation in the summer resulting in higher cooling requirements. This can observe in Figure 7, where the top floor is characterised with the highest requirements for energy use.

Once the block of flats was not planned at first with constructive passive initiatives, the singular use of passive strategies could not facilitate thermal comfort in both the summer and the winter. Thus, a hybrid strategy was introduced. In this sense, passive strategies were implemented in the refurbishment focusing on the envelope insulation. This reduced the energy consumption from 17.5 to 5.1 kWh $m^{-2}y^{-1}$, roughly 70% conforming to the Passivhaus requirements. On the other hand, the effects of the envelope insulation prevented the transference of heat to the outside environment, during the summer, which resulted in a need for additional active cooling incurring in a 2% increase from 19.3 to 19.7 kWh $m^{-2}y^{-1}$ (COSTANZO, EVOLA, *et al.*, 2017). Whilst the energy saved from heating significantly outweighed the slight increase in cooling, this did not follow the compliance with the Passivhaus standards of refurbishments.

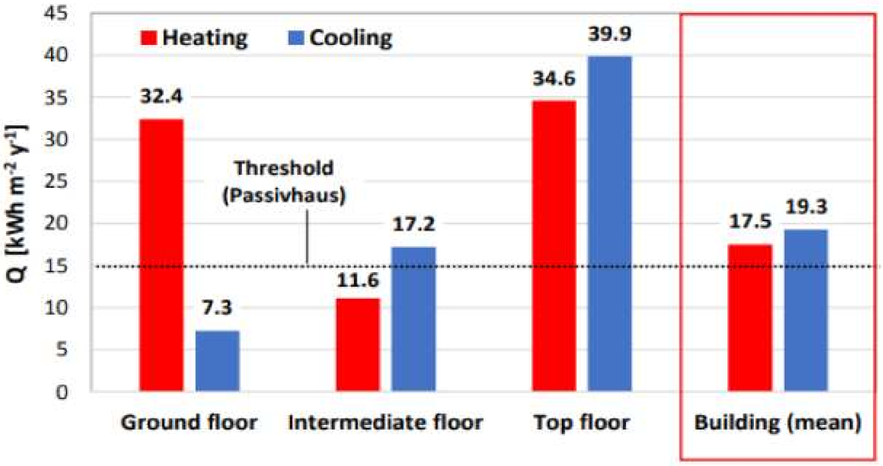


Figure 7- Energy needs for space heating and space cooling before the refurbishment (COSTANZO, EVOLA, *et al.*, 2017)

In this scenario, the overall energy efficiency was significantly improved using a hybrid strategy. Amendments to the passive strategies were performed, e.g., reducing the thickness of insulation in the bottom slab and in the outside walls, treating the outer surface of the envelope with a solar reflective pain, and providing the windows with reflective outer glazing; which resulted in an increase of heating requirements of roughly 30%, from 5.1 to 6.9 kWh $m^{-2}y^{-1}$. However, due to the heating requirements already being below the Passivhaus threshold, these sacrifices were made to reduce the requirements for active cooling. This resulted in a 30% cut of energy needs for active cooling from 19.3 to 13.6 kWh $m^{-2}y^{-1}$. In conclusion, Passivhaus regulations were met (COSTANZO, EVOLA, *et al.*, 2017), as seen in Figure 8:

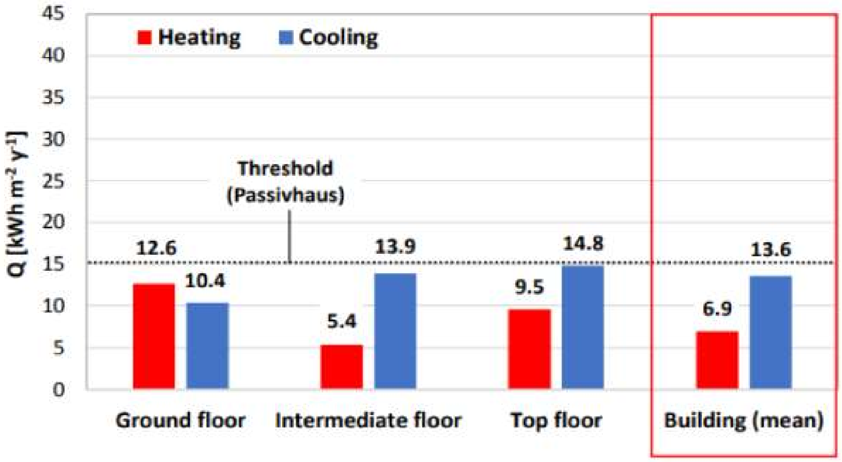


Figure 8 - Performance of the building in the final configuration (COSTANZO, EVOLA, *et al.*, 2017)

Refurbishing a building under the constraints of a regulation to improve energy efficiency and thermal comfort, from climate to climate, is an achievable task. However, it can require a more complex and elaborate strategies. The example demonstrated in Sicily, Italy, highlights the importance of balancing both passive cooling and heating strategies whilst also accepting the use of active strategies to fine tune thermal comfort throughout different climates. This application of a hybrid strategy achieved energy efficient outcome whilst complying with the strict Passivhaus regulations for refurbishment.

2.4 Thermal Performance Standards

Thermal performance standards are instrumental in specifying, measuring and evaluating that the thermal comfort attends the needs of the occupants of a building.

The thermal efficiency of the buildings, through the thermal performance standards, can be evaluated by comparing the practical results with the pre-established aspects (pre-defined set of parameters). In this way, it is possible to standardize constructive processes aiming at quality, constructive ease, less waste, attending to users' expectations and to the functionality for which the building will be designed.

Due to differences in the characteristics of each country, whether due to the relief, location, sun exposure, humidity levels, constructive traditions and other specifications, there is a need to adapt processes and constructive parameters to provide buildings with greater efficiency and thermal habitability.

2.4.1 In developed countries

2.4.1.1 UK's Building Regulations

The Building Regulations is responsible for establishing standards for the design and construction of buildings and ensuring the thermal efficiency of the UK housing stock, as well as the health and safety of the occupants. The documents present the minimum requirements to regulate energy conservation in buildings (LABC, 2018). Each of the documents have sections (Table 4) with expected performance guidelines for materials and building work to comply with the Building Regulations. Examples and solutions for achieving compliance with different building situations are also addressed in the regulations (GUARDIAN PLUS , 2013).

Table 4 – Approved Documents and Technical Guidance for England and Wales

Parts	**Approved Documents (England and Wales)**		
A	Structure	**J**	Combustion appliances and fuel storage systems
B	Fire safety	**K**	Falling, collision and impact
C	Site preparation and resistance to contaminants and moisture	**L**	Conservation of fuel and power
D	Toxic substances	**M**	Access to and use of buildings
E	Passage of sound	**P**	Electrical safety
F	Ventilation	**Q**	Security
G	Sanitation and water	**R**	Electronic communications infrastructure
H	Drainage and waste disposal	**7**	Materials and workmanship
N	Glazing*		

*For use in Wales. Adapted from (LABC, 2018)

Events, such as the Great Fire in 1666 in London caused a concern to improve the buildings fire resistance, as well as the disorderly growth of cities. These events resulted in specific local building standards introducing consistency to the existing standards (KILLIP, 2005). In this context, the 1875 Public Health Act spurred the creation of a number of local laws and, as mentioned by DOWNSON, POOLE, *et al.*, (2012), who reinforced that public health issues at the time were stronger than the need for the improvement of energy efficiency of buildings.

Thus, in 1936, the first single model series of control appeared in the British standards, but still, it was not mandatory (KILLIP, 2005). The first Building Regulations of compulsory application was introduced in 1966, revised in 1972 and also later in 1976. In 1985, The Building Regulations came to include the modern building control system, which underwent revision in 2000 (KILLIP, 2005). In the 1976 review, there was a concern to limit the heat loss through the enveloping components such as walls, roofs and floors in new housing. The different editions of the regulations have tightened the targets to avoid the heat transfer on new buildings (DOWNSON, POOLE, *et al.*, 2012).

In subsequent years, the Building Regulations underwent several revocations (See annex •A), amendments and approvals of new documents. Some approvals are applicable for the entirety of the UK and Ireland, but may vary from country to country. For example, regulations regarding energy and fuel conservation in buildings are often revised as the 2010 edition incorporated amendments of 2010, 2011, 2013, 2016 and 2018, bringing a new rearrangement in the structure of regulations, for the use in England specifically (HM GOVERNMENT, 2010). Predictions for future reviews are intended to improve energy efficiency and set "zero carbon" and "net carbon" targets for all developers by using modernity, technology and efficient systems (DOWNSON, POOLE, *et al.*, 2012).

2.4.1.2 United States' ASHRAE

In the United States (US), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) funds research projects, supplies continuing education, and develops technical standards to improve the methods relating to energy efficiency, thermal comfort, building services engineering, and sustainable development. ASHRAE also publishes sets of standards and guidelines relating to HVAC systems and issues that are often referenced in building codes, government agencies, architects and consultancies worldwide (ASHRAE, 2010).

Most noticeably, regarding thermal comfort, ASHRAE's Standard 55: "Thermal Environmental Conditions for Human Occupancy" (2010) establishes thermal comfort within indoor environments. This standard outlines ASHRAE's fundamental research concerning four primary environmental factors: temperature, humidity, air flow/speed and thermal radiation; and two, more personal, factors: clothing and activity. It was first published in 1966, and since 2004 it has been updated every three to six years. The most current standard was published in 2017.

As described within the ASHRAE Standard 55 (2010) itself, the purpose of the standard is to "specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space". The standard evaluates the versatile conditions of both the human occupancy and the environmental climate. In section 7, the standard highlights the need to evaluate the thermal environment at the design stage taking into consideration the local climate and how this will direct the design strategies. Also, under “Compliance”, Section 6, it is suggested that some of the requirements may not be applicable to naturally conditioned buildings (ASHRAE, 2010).

In regards to the varied occupancy which may use the dwelling or workspace, a literature review on the responses of disabled persons to thermal environments was conducted (ASHRAE, 2000). Once extensive testing was completed, comparisons were made to Standard 55 with the aim of continued adaptation to accommodate varied circumstances.

2.4.2 Brazil

In Brazil, the Brazilian Association of Technical Standards (ABNT) is the national standardization forum, a private and non-profit entity. ABNT is a founding member of the International Organization for Standardization (ISO). The association is responsible for the elaboration of Brazilian standards (ABNT NBR) and acts in the evaluation of the conformity and certification of products, systems and environmental labelling (ABNT, 2014).

In 1985, the regulations for improving energy efficiency in buildings were approved in Brazil, through the National Electricity Conservation Program (PROCEL), with the aim of objectifying the rationalization of the production and consumption of electricity (D'ELL SANTO, DE ALVAREZ e NICO-RODRIGUES, 2013). Nowadays, the main standards that address the thermal behaviour of a residential building in Brazil are ABNT NBR 15220 (2005) and ABNT NBR 15575 (2013)

2.4.2.1 ABNT NBR 15220 – Thermal Performance in Buildings

The ABNT NBR 15220 (2005), entitled "Thermal Performance in buildings", became valid in 2005. The second section of the standard: "Part 2 - Calculation methods of thermal transmittance, thermal capacity, thermal delay and solar heat factor of elements and components of buildings" was last edited on 06/09/2008. From its publication, a standardization was created to define constructive characteristics with the aim of obtaining improvements in the thermal performance of Brazilian buildings. This standard is divided into 5 parts (Table 5):

Table 5 – Main sections within the ABNT NBR 15220 Standard

Parts	ABNT NBR 15220 – Thermal Performance in buildings
1	Terminology, symbols and units
2	Calculation methods of thermal transmittance, thermal capacity, thermal delay and solar heat factor of elements and components of buildings
3	Brazilian bioclimatic zones and building guidelines for low-cost houses
4	Measurements of the thermal resistance and thermal conductivity by the guarded hot plate apparatus
5	Measurement of the thermal resistance and thermal conductivity in steady state by the fluximetric method

Adapted from: (ABNT, 2005)

Among other aspects, the standard establishes Brazilian Bioclimatic Zones and constructive strategies for single-family dwellings of up to three floors, including for Low-Income Housing (LIH). The standard defines strategies of passive thermal conditioning, based on fixed parameters and boundary conditions. The part 3 of the NBR 15220 is not obligatory but directional. Also, it references ASHRAE (1996) - Algorithms for Building Heat Transfer Subroutines.

2.4.2.2 ABNT NBR 15575 – Residential Buildings - Performance

The standard ABNT NBR 15575 (2013), entitled "Residential Buildings - Performance", is applicable for buildings with no limitations of floors, and had its first edition in 2008, subsequently in 2010 and then, in the latest version, became valid in 2013. The standard has the pretension of meeting the expectations of the users regarding the systems that make up their dwellings, independent of the constructive system adopted (2013). The focus of the standard is related to the expectations of the users for the residential buildings and its systems. That is, the demands of the users regarding the behaviour of the buildings in use and not a guideline of how systems should be built.

According to the Brazilian Chamber of Construction Industry – CBIC (2018), the Brazilian standard enabled the evaluation of the quality of the building's systems and materials, and the benefits provided to the consumer through transparent procedures. Thus, the standard modifies the way of designing the project, as well as the way in which services are hired and the products are chosen (OLIVEIRA e MITIDIERI FILHO, 2012). This standard seeks to meet the desired thermal performance (minimum - required, intermediate or higher - optional), according to the needs of the user, through aspects such as (CHVATAL, 2014):

- Structural, thermal, acoustic and luminous performance;
- Watertightness;
- Functionality, accessibility and durability (design life and warranty);
- Safety in use and operation, the structural integrity and resistance to fire;
- Tactile and anthropodynamic comfort, health, hygiene and air quality;
- Maintenance management.

The NBR 15575 is not a prescriptive standard. Performance standards are considered complementary to the prescriptive standards which in turn establish requirements based on the use of products and procedures. The simultaneous use of both types of standards provides technically appropriate solutions and if there is a divergence between the two, all requirements in both should be followed (ABNT, 2013). Thus, some concepts not covered in the prescriptive standards such as system durability, maintenance, tactical comfort and anthropodynamics of users are addressed in the performance standards (ABNT, 2013). The ABNT NBR 15575 (2013) is informative and standardised in nature and is divided into 6 parts (Table 6):

Table 6 - Main sections within the ABNT NBR 15575 Standard

Parts	ABNT NBR 15575 – Residential Buildings - Performance
1	General requirements
2	Requirements for structural systems
3	Requirements for floor systems
4	Requirements for internal and external wall systems
5	Requirements for roofing systems
6	Requirements for hydrosanitary systems

Adapted from: (ABNT, 2013)

3 METHODOLOGY

To obtain the proposed objective, the thermal performance standards described in Table 7, were analysed and compared. They originate from the United Kingdom and Brazil, in order to understand the differences in their policies for thermal comfort.

Table 7 - Thermal performance standards to evaluate the thermal performance of buildings

Country	Year	Thermal Performance Standards
Brazil	2005	ABNT NBR 15220 – Thermal Performance in Buildings
Brazil	2013	ABNT NBR 15575 – Residential Buildings - Performance
UK	2010	The Building Regulations – L (L1a, L1b,L2a,L2b)

The understanding of these differences was based on the qualitative comparison of parameters and published data, as well as on how those policies affect the quality of the thermal performance standards for buildings in each country analysed. In this sense, the first concern was to choose parameters directed to the most relevant topics of the comparisons, without neglecting the local characteristics of each country.

After identifying possible drawbacks, including the energy efficiency of buildings in different climates, the challenges faced by Brazil were outlined. On top of this, the possible issues of outdated thermal performance regulations and the resulting impacts on buildings, health and the satisfaction of users were defined. Finally, after understanding the effectiveness of the thermal performance standards, comparisons were made to establish what can be learned by Brazil with the promising solutions adopted by other countries.

4 RESULTS AND DISCUSSION

4.1 Parameters evaluated by Brazilian and British performance standards

Despite the qualitative character of the present analysis, some parameters addressed by the thermal performance standards, discussed in this work, are attributed to the quantitative performance evaluation of the building envelope, or even the quantitative performance of the building as a whole. Therefore, it is fundamental to define these parameters to allow the interpretive and contextual analysis intended.

a) **U-Value or Thermal transmittance (W/m^2.K):** The rate of heat transfers through an element. The lower the U-value, the less heat is transferred. E.g. “a U-value of 6.0 W/m^{2}K (that of a single glazed window) means that six watts will be escaping through each square metre of glass when the temperature difference is one degree” (CAT, 2018).

b) **Thermal conductivity (W/ m.K):** The ability of a material to conduct greater or lesser amounts of heat per unit of time. The variable is dependent on the density of the material (LAMBERTS, DUTRA e PEREIRA, 2012). E.g. “The thermal conductivity of copper at room temperature is =700 times greater than that of water and = 3000 times greater than that of engine oil” (CHOI e EASTMAN, 1995).

c) **Thermal resistance (m^2.K/W):** The material property related to its heat resistance. E.g. The greater the thickness of a material, the greater its resistance to the passage of heat. Likewise, a material with a high thermal conductivity will have lower thermal resistance (LAMBERTS, DUTRA e PEREIRA, 2012).

d) **Thermal bridges:** “Components within the envelope whose thermal insulation properties are lower than those of the surrounding material” (SIGNS, 2010). E.g. Metal components. They may impair de thermal insulation of a system by conducting heat more significantly than the other materials of this arrangement.

e) **Thermal Lag (Hours):** “Time elapsed between a thermal variation in an element and its manifestation on the opposite surface of a constructive component subjected to a periodic regime of heat transmission" (ABNT, 2005).

f) **Solar Gain Factor:** Quotient of the rate of solar radiation directly transmitted through a component by the rate of total solar radiation incident on its external surface (ABNT, 2005). E.g., for a single glass window, which solar factor is on average 0.87, 87% of incident solar radiation penetrates the interior (LAMBERTS, DUTRA e PEREIRA, 2012)..
g) **Emissivity:** Quotient of the radiation rate emitted by a surface by the radiation rate emitted by a black body at the same temperature (ABNT, 2005). That is, emissivity is the ability of an object to emit electromagnetic radiation when compared to a black body (object that absorbs all radiation, at all wavelengths).
h) **Absorptance:** Quotient of the rate of radiation absorbed by a surface by the rate of radiation incident on this same surface (ABNT, 2005). E.g. A dark material when compared to a light material absorbs most of the incident radiation (LAMBERTS, DUTRA e PEREIRA, 2012).
i) **Specific heat (J/Kg.K):** "A measure of the amount of heat required to raise the temperature of a given mass of material by 1°" (GRONDZIK, KWOK, *et al.*, 2010). E.g. A low-specific-heat material requires less energy input to raise its temperature than a high-specific-heat material (GRONDZIK, KWOK, *et al.*, 2010).
j) **Thermal capacity (J/m^2.K):** It is the product between the specific heat and the mass of a material, and it represents the ability of an element to retain heat. E.g., an element with high thermal capacity needs a high amount of heat to promote the variation of a temperature degree in its components per unit area (LAMBERTS, DUTRA e PEREIRA, 2012).
k) **Apparent density (Kg/m^3):** The ratio of mass to apparent solid volume of a material (including the permeable voids) (ABNT, 2005).
l) **Airtightness:** Defined in terms of Air Permeability, represents "the volume flow rate of air per square metre of building envelope and floor area at a given pressure" (SIGNS, 2010).

4.2 Review of Brazilian Standards

4.2.1 ABNT NBR 15220 – Thermal Performance in Buildings

The NBR 15220 (2005), in Part 3, divides Brazil into eight bioclimatic zones (Figure 9), relatively homogeneous. The standard brings data from 330 cities that had their climates classified and the methodologies adopted to determine this zoning. Some of the boundary conditions taken into account to determine the constructive guidelines of each zone are: the size and shading of ventilation openings, materials selection for external walls and roofing (with characteristics such as thermal transmittance, thermal delay and solar factor) and passive strategies of thermal conditioning.

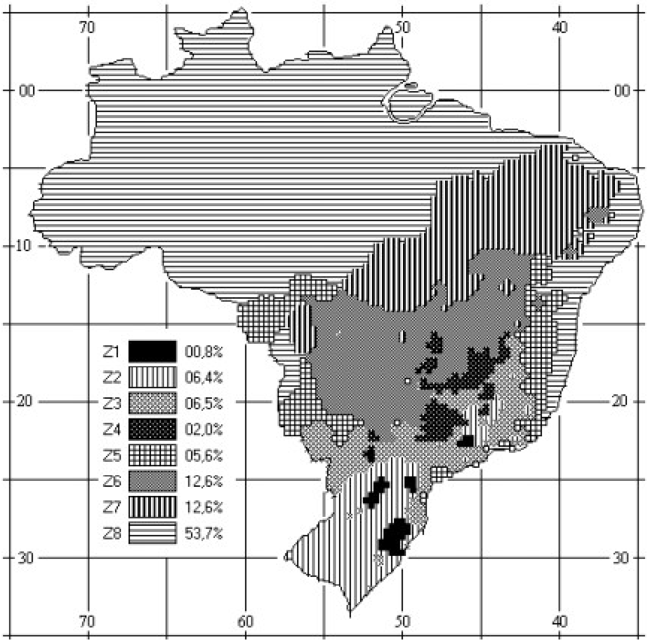


Figure 9 - Demonstration of the Brazilian climatic zoning. Adapted from ABNT (2005).

The standard is based on the bioclimatic chart of GIVONI (1992) and is restricted to single-family Low-Income Housing in Brazil. Some variables such as: monthly average temperatures (maximum and minimum) and monthly average air relative humidity were used as a climatic data base for dividing the Brazilian territory into cells for calculation.

According to NBR 15220 (2005), the evaluation of the thermal performance of a building can be carried out in the design phase, through computational simulations or through the verification of a set of guidelines; or after construction, through in situ measurements of significant variables. Contrary to what the name suggests, the standard does not address procedures for evaluating the thermal performance of buildings but provides guidelines for achieving at least minimal performance without presenting a verification method. In this sense, for each of the established zones, the standard aims to optimize the thermal performance of buildings through climate suitability.

The annexes to part 3 of the standard contain recommendations for constructive guidelines for ventilation openings, U-values, thermal delay and solar gain factor of external walls and roofs. Other characteristics such as thermal transmittance, thermal capacity and thermal lag of some walls and roofs are also specified in the annexes.

The constructive guidelines indicated by the standard can be summarized in Table 8, where the following units were used: U - Thermal transmittance (W / m^2K); Φ - Thermal Lag (Hours); SF_o - Solar gain factor of opaque surfaces; TF - Acceptable Transmittance Correction Factor for roofs located in Zone 8. The terms “heavy wall”, ”light wall”, “light isolated” and “reflective light wall” are associated to these parameters limits.

Table 8 - Constructive guidelines defined by the ABNT NBR 15220 Standard

Zone	**Strategies**		**Ventilation openings (% of floor area)**	**Shading of openings**	**Wall**			**Roof**		
	Summer	**Winter**			U	Φ	SF_o	U	Φ	SF_o
1		Solar heating of the building / Heavy internal walls (thermal inertia)	Medium 15%<A<25%	Allow sun only during winter	≤3 Light wall	≤4.3	≤5.0	≤2.0 Light isolated	≤3.3	≤6.5
2	Cross-ventilation	Solar heating of the building / Heavy internal walls (thermal inertia)	Medium 15%<A<25%	Allow sun only during winter	≤3 Light wall	≤4.3	≤5.0	≤2.0 Light isolated	≤3.3	≤6.5
3	Cross-ventilation	Solar heating of the building / Heavy internal walls (thermal inertia)	Medium 15%<A<25%	Allow sun only during winter	≤3.6 Reflective light wall	≤4.3	≤4.0	≤2.0 Light isolated	≤3.3	≤6.5
4	Evaporative cooling and thermal inertia for cooling / Selective ventilation in hot periods, when the internal temperature is higher than the external temperature	Solar heating of the building / Heavy internal walls (thermal inertia)	Medium 15%<A<25%	Shade openings	≤2.2 Heavy wall	≤6.5	≤3.5	≤2.0 Light isolated	≤3.3	≤6.5
5	Cross-ventilation	Heavy internal walls (thermal inertia)	Medium 15%<A<25%	Shade openings	≤3.6 Reflective light wall	≤4.3	≤4.0	≤2.0 Light isolated	≤3.3	≤6.5

Zone	Strategies		Ventilation openings (% of floor area)	Shading of openings	Wall			Roof		
	Summer	Winter			U	Φ	SF_o	U	Φ	SF_o
6	Evaporative cooling and thermal inertia for cooling / Selective ventilation in hot periods, when the internal temperature is higher than the external temperature	Heavy internal walls (thermal inertia)	Medium 15%<A<25%	Shade openings	≤2.2 Heavy wall	≥6.5	≤3.5	≤2.0 Light isolated	≤3.3	≤6.5
7	Evaporative cooling and thermal inertia for cooling / Selective ventilation in hot periods, when the internal temperature is higher than the external temperature		Small 10%<A<15%	Shade openings	≤2.2 Heavy wall	≥6.5	≤3.5	≤2.0 Heavy	≤6.5	≤6.5
8	Permanent Cross-ventilation. Passive conditioning will be sufficient during warmer hours		Big A>40%	Shade openings	≤3.6 Reflective light wall	≤4.3	≤4.0	≤2.3. FT Reflective light	≤3.3	≤6.5

Adapted from (LAMBERTS, DUTRA e PEREIRA, 2012)

The part 2 of NBR 15220 (2005) provides equations and procedures for the calculation of thermal transmittance (U) , thermal resistance, thermal capacity (TC), thermal lag (Hours) and solar gain factor of opaque, transparent, or translucent components of buildings. In the annexes, average values are recommended for surface thermal resistance and non-ventilated air chambers, as well as variables such as emissivity, absorptance, apparent mass, thermal conductivity, specific heat, to then provide calculation examples for conventional building materials.

The part 4 of the standard presents the “guarded hot plate method” for determining the resistance and thermal conductivity of solid or granular materials. At the same time, design criteria, dimensions and tolerances (minimum requirements) for equipment are addressed. Likewise, test conditions such as: measurement procedures, preparation of test specimens (especially for low-density specimens) and materials used in construction, as well as information to be included in test reports, are included part of the standard.

Finally, in part 5, a method for measuring the thermal conductivity using a flow meter is described. The method is relative and requires a periodic pre-calibration of the apparatus. Some recommendations for the test report are also established.

4.2.2 ABNT NBR 15575 – Residential Buildings – Performance

The NBR 15575 (2013) deals with the thermal performance of buildings up to five floors and their systems, how their behave when used, aiming at meeting the requirements of users. Relative criteria for thermal performance, acoustic, light and fire resistance are addressed in the standard. In the following paragraphs, the main requirements of this standard regarding thermal performance are presented.

4.2.2.1 Part 1: General requirements

In the first part of the standard, general requirements and definitions of the main used terms are established. Stakeholder assignments such as the identification of the risks of the work, determination of the projected lifespan and the preparation of the operation are also defined. The standard requires the operation and maintenance manual to be delivered to the owner with the new building. In terms of performance evaluation, this part of the standard raises issues such as the importance of assessing the environment and the viewpoint regarding the safety of the structure during its lifespan.

Also on the first part, the section dedicated to thermal performance brings two types of procedures for the evaluation of the thermal performance – the “Simplified” one, required, and the “Measurement” one, informative. If the result on the “Simplified” method is unsatisfactory, the designer can choose the computational method and evaluate the thermal performance of the building as a whole.

In the ‘Simplified’ (required) procedure, the verification of the requirements for roofing and walls systems is made, according to parts 4- Requirements for internal and external wall systems and 5 - Requirements for roofing systems, of the NBR 15575 standard. One option is to adopt a computer simulation of the building to verify if it meets the criteria of air temperature limitations established. This simulation is done on the basis of tables attached to the annexes of this part of the standard, the geographical location and climatic data of some Brazilian cities. If the city data is not included, the use information of nearby cities located in the same bioclimatic zone of NBR 15220-3 (2005) is recommended. In the persistence of insufficient data, it is recommended not to use the computational method.

Regarding the requirements for computational simulation, the standard considers performance requirements in summer and winter period, through the statistical treatment of maximum and minimum values of temperature. NBR 15575-1 does not differ temperature limits for buildings with natural or mechanical ventilation. Thus, some considerations for thermal critical conditions, such as window orientation, shading devices, obstruction in the surroundings, material for covering and absorbance of solar radiation, through the definition of colours on exposed surfaces, are present in the recommendations. In order to perform the computational simulations, NBR 15575-1 suggests the use of the *EnergyPlus* software and calculations made for one design day, for summer and winter.

In the second procedure, “Measurement” (informative), a verification is made if the specified requirements are being met in NBR 15575-1 by measurements *in situ* or through prototypes. Because it is informative, it does not overlap with the procedures in the first method.

4.2.2.2 Part 2: Requirements for structural systems

In part 2 of NBR 15575 (2013), it is suggested that the Part 1 should be verified for the evaluation of thermal performance.

4.2.2.3 Part 3: Requirements for floor systems

Part 3 of the standard does not establish isolated thermal performance requirements for floor systems and suggests that, for a global analysis of thermal performance, the Part 1 should be verified.

4.2.2.4 Part 4: Requirements for internal and external wall systems

Part 4 of NBR 15575 (2013) provides criteria for verifying the minimum thermal performance of external and internal walls. These systems can be evaluated through fixed performance requirements considering the simplified analysis procedures. If the criteria analysed is not met, it is necessary to apply the procedures cited in the Part 1 by simulation or on-site measurements. If the computational simulation method is adopted, the ventilation and shadowing conditions must be adopted according to NBR the Part 1. For ventilation, it is possible to use a "typical condition" or a "ventilated condition" by varying the air renewal rate per hour of the rooms. The same applies to shading, where the "typical condition" represents the lack of protection of the openings against the entrance of solar radiation, and the "shaded condition" represents a minimum of 50% of the solar radiation incident in the rooms. Although the whole building must be simulated, the standard only requires evaluation of the temperature responses in “rooms of prolonged standing” - living rooms and bedrooms.

This part of the standard brings requirements for values of thermal transmittance and thermal capacity to obtain the minimum thermal performance for each bioclimatic zone present in NBR 15220 - Part 3. The standard specifies that openings in permanent living environments must contain areas that meet specific local legislation. If there are no local requirements, there is an option to use the minimum values presented in this part of the standard.

4.2.2.5 Part 5: Requirements for roofing systems

Part 5 of the NBR 15575 addresses criteria and minimum performance requirements for the roofing. To this purpose, the definitions of NBR 15220 – Part 1 and Part 3 are considered. As a requirement, the limits for thermal transmittance and absorptivity to solar radiation should be appropriate for each bioclimatic zone defined in NBR 15220 – Part 3. The criteria used establishes conditions for the evaluation of the thermal performance by the “simplified thermal performance method”. If the roofing does not meet the requirements of this method, the thermal performance of the building is checked according to the NBR 15575 - Part 1. In the evaluation, the determination of the thermal transmittance must be made according to NBR 15220 – Part 2.

4.2.2.6 Part 6: Requirements for hydrosanitary systems

Part 6 of the NBR 15575 does not establish thermal performance requirements.

4.3 Review of British Standards

4.3.1 The Building Regulations – Part L (England and Wales)

UK’s Building Regulations encompass a set of rules dedicated to all stages of building design and construction work. The regulations provide quality control details and cover various aspects such as drains, sanitation, foundations, and building materials. The present study evaluates the Building Regulations that are enforced in England and Wales. Each regulation is focused on a particular aspect of design and construction. Regarding the thermal performance of buildings, the Building Regulations

- Part L: Conservation of fuel and power (2010), aims to reduce energy consumption and CO_2 emissions of the building stock to an acceptable level. This part focuses on the envelope performance through specifications such as U-values, thermal bridges and airtightness.

In view of this, in the criterion 4 of the part L (2010), provisions are adopted to avoid the effects of the thermal bridges caused by joints, gaps and edges of elements (e.g., around windows and doors). Also, the airtightness relates directly to the requirements of the approved document L, once it can allow improvements to the thermal performance of the envelope without serious increases in the insulation thickness (SIGNS, 2010).

Regarding part L (2010) scope (Table 9), nenhuthe regulations bring distinctions between requirements and guidelines in their sections. This part is divided among four approved regulations:

- Conservation of fuel and power in new dwellings – L1A;
- Conservation of fuel and power in existing dwellings – L1B;
- Conservation of fuel and power in new buildings other than dwellings – L2A;
- Conservation of fuel and power in existing buildings other than dwellings – L2B.

Table 9 – Contents of the Building Regulations – Part L (England and Wales)

L1A and L2A (dwellings)	L1B and L2B (buildings other than dwellings)
Section 1: The requirements	**Section 1:** Introduction
Section 2: Design standards	**Section 2:** The requirements
Section 3: Quality of construction and commissioning	**Section 3:** General guidance
Section 4: Providing information	**Section 4:** Guidance related to building work
Section 5: Model designs	**Section 5:** Guidance on thermal elements
	Section 6: Consequential improvements to energy performance
	Section 7: Providing information

Adapted from: (HM GOVERNMENT, 2010)

For a new building, dwelling or non-dwelling, the respective regulations require the delivery of certificates of energy performance by those who have carried out the work of erecting the building to the owners. Likewise, for an existing building, dwelling or non-dwelling, a certificate confirming that the work performed complies with the requirements of the building regulations must be given to the occupants within 30 days of completing the work.

Beyond the envelope aspects, the regulations have a global meaning for the energy performance of dwellings and buildings other than dwellings, not only regarding the efficiency of heating systems but also related to fuel issues and its tariffs. In this sense, systems specifications, following the recommendations of the manufacturers, are not sufficient if the building calculation models such as: the “Simplified building energy model” (SBEM) (for no-dwellings) or the “Standard Assessment Procedure” (SAP) (for dwellings) are not followed (SIGNS, 2010).

The SAP is an approved UK national calculation methodology to classify the energy performance of buildings. The method uses basic parameters of building performance and estimates, through tables and correlations, for example, the emission of CO_2 by the dwellings. This calculation is based on parameters such as: U-values, air tightness level, mechanical systems (fans, pumps, etc.), lighting systems, hot water systems, performance of space heating and savings associated with renewable technologies (DOWNSON, POOLE, *et al.*, 2012). Once the parameters are entered into the calculation tool, the assessment shows if the dwelling is in compliance when the values found indicate a "medium" or "low" risk. If the evaluation indicates a "high" risk, there is no compliance with the criteria in part “L1A” and “L1B” (BATESON, 2016).

In this sense, the Target CO_2 Emission Rate (TER) and the Target Fabric Energy Efficiency (TFEE) rate, present in the section 2 of regulations (L1A and L1B) which are, respectively, the mass of CO_2 expressed in kg/m^2/year and the amount of energy demand in KWh/m^2/year, represent the minimum energy performance requirements for dwellings to be calculated and approved according to the SAP.

The SBEM, a computer program developed by BRE - Building Research Establishment (based in the UK but involved with international work), is also used to determine the TER in compliance with part L and generates the energy performance certificates for non-dwellings on construction, for sale or rent (BRE, 2018). The SBEM applies for non-dwellings with design features which can be modelled by the software and it is available free of charge from the internet.

Part L regulations (2010) generally addresses the requirements for fuel and energy conservation and the renovation or replacement of thermal elements, as well as compliance criteria. In this sense, some criteria in the regulations for dwellings are a function of the thermal performance of the envelope. For example, in criterion 3, regulation L1A defines the approach to the limits for summer heat gains, as well as their effects. These limits are associated to the window size and orientation, ventilation (day and night), and thermal capacity. In the same section, it is discussed the losses and heat gains from circulation pipes.

4.4 Main comparisons between the Standards

The comparative analysis of the Brazilian standards and the UK Building Regulations – Part L were based on parameters considered consistent for the thermal performance of buildings. The summary of the aspects included or absent in each standard is shown in Table 10:

Table 10 – Comparative table of the thermal performance standards

Specified Aspects	**Brazilian Standards**		**UK Standards**
	ABNT NBR 15220 (2005)	**ABNT NBR 15575 (2013)**	**The Building Regulations - L (2010 with 2018 amendments)**
Current Updates	✗	✗	✓
Performance Certificate	✗	✗	✓
Operation and maintenance manual	✗	✓	✓
Climate and Bioclimatic Zones	✓	✓	✗
U - Values	✓	✓	✓
New dwellings	✓	✓	✓
Existing dwellings	✗	✗	✓
Buildings other than dwellings	✗	✗	✓
Calculation of CO_2 emission rate	✗	✗	✓
Simulation Procedures	✗	✓	✓
Design Life (working life span)	✗	✓	✗
Limits for heat gains in summer	✓	✓	✓
Building Orientation and shading	✗	✓	✗
Passive strategies	✓	✗	✓
Insulation requirements for floor systems	✗	✗	✓
Available for free access (pdf)	✗	✗	✓

4.5 Critical analysis of the thermal performance standards

In populous countries, such as Brazil, the demand for electricity in buildings increases as urban development intensifies. This growing demand for energy, which massively contributes to CO_2 emissions, is largely devoted to remedying deficiencies in the thermal comfort of buildings. In this situation, the requirements of building standards play a relevant role in ensuring the thermal and general performance of buildings.

The Brazilian standards dedicated to the thermal performance of buildings, NBR 15220 (2005) and NBR 15575 (2013), are relatively new when compared to other standards in countries such as the United Kingdom and United States. When analysing the frequency of editions and updates of the standards, it is possible to notice a great discrepancy between UK and Brazil, once the Brazilian standards are rarely updated. The NBR 15575 (2013) despite having four versions prior to its publication in 2013, did not release any updates since that year. In the same way, the NBR 15220 (2005) has not been updated for over 10 years. On the other hand, the Building Regulations, in the UK, go through a constant process of adaptations almost every year, with considerable iterations for energy efficiency showed in 1976, 1985, 1990, 1995, 2002, 2006 and the latest in 2013. This constant revising enables it to reinforce and distinguish technical and interpretational aspects whilst also including new approaches.

Another distinctive aspect of both countries standards is the practical type of construction for which they apply. The Brazilian standards NBR 15220 (2005) and NBR 15575 (2013) are restricted to new dwellings, in the design phase, and there is no mention of other types of buildings in different construction phases. This approach is strongly simplified, since it does not offer alternatives to improve the thermal performance of the Brazilian traditional housing stock, neither commercial or industrial buildings. In contrast, the UK's Building Regulations - Part L (2010) sets forth regulations for new and existing dwellings and for new and existing buildings other than dwellings, showing a greater concern to encompass different possibilities.

In both the NBR 15575 and the UK's Building Regulations - Part L, specifications such as the creation of an operation and maintenance manual, to be delivered to the owners/occupants is present. In this sense, the UK's Building Regulations - Part L also addresses the delivery of a performance certificate to the building owner. These inclusions reinforce the responsibility of the builders and designers and the reduction of some subjective criteria while following the standards, as well as approaches to achieve building quality control.

Another one of the few characteristics present in the Brazilian standards but not in the UK's Building Regulations - Part L, is the consideration of the bioclimatic zones as an influencer of thermal efficiency. In this sense, the UK's Building Regulations – Part L (2010) does not specify bioclimatic zones but considers thermal performance as a function of variables such as U-values, thermal bridges and air tightness. On the other hand, the climatic differences between Brazil and the United Kingdom are evident. Brazil has a considerable larger territory, which culminates in wider climatic variation and different specifications, from city to city, when compared to the cities in the UK, which share a similar average temperature. For this reason, the systematic division of the territory into bioclimatic zones is an interesting approach to the Brazilian context. However, some authors such as AMORIM e CARLO (2017) consider the bioclimatic proposal outdated and limited, since it does not always present positive results for certain situations, for example, of nearby cities with different topography and climate characteristics classified in the same bioclimatic zone. In this context, the need for revision of the NBR 15220 is constantly reinforced, since it has been published more than 10 years ago, and continues to be used without consistent updates.

Regarding the performance of buildings, the UK's Building Regulations – Part L quantifies the energy performance in terms of CO_2 emissions combined with the building energy requirements. This approach is beneficial for reducing the operational energy usage in buildings and also contributes towards the consideration of the buildings global performance, rather than just the specific thermal properties of the components within the envelope. On the other hand, the NBR 15575 (2013) disregards the variation of behaviour from the users and the use of heat-producing equipment that contributes to CO_2 emissions. Thus, the methodological guidelines of NBR 15575 (2013) are simplified and vulnerable, since they do not consider the varied conduct of the users and how this may affect their thermal comfort.

The energy efficiency of the building envelope is a function of several parameters, among them the U-values which shows how effective a material is as an insulator. This parameter is present in both Brazilian standards and also in the UK's Building Regulations - Part L. However, the Brazilian standards limits are not as ambitious as the UK's higher standards of compliance (Table 11), especially within new dwellings, where the UK aims to achieve U-values up to twenty-eight times lower (worse case scenario), for walls and roofs. As a consequence of this difference, the Brazilian dwellings hold relatively worse thermal insulation performance. Thus, this deficiency reflects in dissatisfaction from the users, a higher electricity consumption to maintain the thermal comfort of buildings and, consequently, contributes to higher CO_2 emissions, during summer and winter. In this case, the reduction of the U-values of the components in the Brazilian standards, as well as the consideration of the use and occupation in the analyses, can contribute to a more realistic thermal behaviour and an improved thermal performance of the building.

Table 11 – Limiting U-values for building components in Brazil and the UK

	ABNT NBR 15220[1]	**ABNT NBR 15575[2]**	**The Building Regulations – L[3]**			
			ND	**ED**	**NBOTD**	**EBOTD**
Wall	2.20	2.50, zones 1-2	0.15	0.30	0.23	0.30
		3.7 ($\alpha^a \leq 0.6$) 2.5 ($\alpha^a > 0.6$), zones 3-8				
Roof	2.00	2.30, zones 1-2	0.13	0.18	0.15	0.18
		2.3 ($\alpha^a \leq 0.6$) 1.5 ($\alpha^a > 0.6$), zones 3-6				
		2.3 ($\alpha^a \leq 0.4$) 1.5 ($\alpha^a > 0.4$), zones 7-8				

[1] U - values for worst case (wall and roof classified as "heavy")

[2] U-values depends of the bioclimatic zones

[3] ND – new dwellings; ED - existing dwellings; NBOTD – new buildings other than dwellings; EBOTD – existing building other than dwellings.

Adapted from: (ABNT, 2005), (ABNT, 2005) and (HM GOVERNMENT, 2010).

Concerning the U-values, the UK Building regulations – Part L attributes thermal transmittance limits to various systems (See annex B) such as walls, roofs, windows, doors, party walls and floors. On the other hand, the NBR 15575 only establishes U-values for walls and roofs, excluding, for example, floors requirements. Although in Brazil, the use of insulation or artificial heating systems for floors is not common, an elaborated analysis of this system can contribute to the efficiency of the envelope, since the floors are significant contributors to the heat exchanges in a dwelling. Thus, concepts of heat exchanges in systems such as floors, windows, doors and structures should be included in Brazilian thermal performance standards.

That being said, the creation of NBR 15575 (2013) brought aspects not previously covered by the NBR 15220 (2005) . In this context, concerns such as the design life of the building or the approach to meeting the requirements of users, regarding the building and its systems, were incorporated. Despite only the NBR 15575 being mandatory, it is possible to observe that these two Brazilian thermal performance standards do not conform to all similar aspects. Some approaches are repetitive but disagree in terms of prescription, making it difficult to follow both standards as complementary. The minimum values for the parameters presented by one standard should be followed by the other. However, the NBR 15220 (2005) presents a greater variance than the NBR 15575 (2013). Likewise, the same parameters should be approached, however limits for SF_o and φ were not included for the thermal transmittance analysis in the NBR 15575. In this context, one of the barriers is the fact that the existence of these two standards to be followed implies in costs to purchase both. Also, it can be difficult for designers to correlate both standards adequately when the descriptions are not equivalent and consecutive.

Brazilian standards and the Building Regulations – Part L in the United Kingdom present computational simulation methods for the evaluation of thermal performance. In NBR 15575 the computational simulation procedure, which considers maximum and minimum values of temperature for summer and winter, does not differ these limits for buildings with natural or mechanical ventilation. Another relevant aspect is that the simulation period, for buildings in the design phase, is limited to simply one design day for winter and one for summer. This shows an extremely simplified situation of analysis and possible distorted results, since the design days are not necessarily the hottest days of the year, but an average, which may not represent the use situation of the building.

On the other hand, the Building Regulations - Part L presents more consistent and complementary methods of compliances. Among them: an elemental method, which treats each fabric building element separately (through U-values); a target parameter method, which takes in consideration the effect of heating systems, solar gains, insulation of individual elements and areas of components such as windows, doors and rooflights; and finally the carbon dioxide targets, which is determined using a notional building of the same size and shape of the actual building, including differentiations for heated and cooled buildings.

The NBR 15220 does not address the orientation of the building, only makes a simple mention that the correct orientation can optimize its heating in the winter through the incidence of solar radiation. On the other hand, NBR 15575 specifies recommendations for simulations of the most critical orientation, from the viewpoint, for summer, winter, and obstruction by constructive elements or in the surroundings. In a similar fashion to NBR 15220, the UK Building Regulations - Part L, directs designers to orientate buildings to the South, in order to benefit from solar passive gains. The standard doesn’t go into further details and has been criticized for overlooking this aspect, whereas the German Passivhaus standard follows passive solar design principles. Thus, the orientation of the building can assist in the reduction of discomfort caused by, for example, high incidence of solar gains on the envelope. However, it’s necessary to attribute passive strategies such as evaluating the microclimate and site design, the building layout and the modulation and heat dissipation techniques to compensate the opposite portion of the house which does not benefit from the passive solar gains granted by the orientated components.

5 CONCLUSION

The present work discussed the differences between the Brazilian thermal performance standards: NBR 15220 (2005) and NBR 15575 (2013) and the UK Building Regulations – Part L (2010). They have set out reasons for believing that the mentioned Brazilian standards are outdated and limited to fulfil their respective roles of informative and standardised guides.

The reasons are:

- The Brazilian standards are relatively young (established in the 2000s) and only have a few updates over the years, to adapt to the new constructive techniques and robust climatic changes;
- They specify broad limits for their insulation parameters when compared to more advanced and up-to-date standards such as the UK Building Regulations – Part L;
- Attributions of thermal performance to different types of buildings other than dwellings, and in different construction phases, other than in the design phase, are not addressed in the Brazilian standards;
- Simulation methods suggested by the Brazilian standards are questionably simplified in terms of temperature limits, time range and do not address the impact of human and machinery occupancy, in terms of heat gain, on the thermal comfort of buildings;
- Their approaches to building orientation associated to passive strategies are minimal to improve the energy requirements of buildings;
- The NBR 15575 (2013) guidelines for different building systems, when existent, only refer to simplified simulations.
- The Brazilian thermal performance standards present significant barriers to be faced by the designers. The existence of two standards to be followed implies in costs to purchase both. Also, the descriptions are not equivalent and consecutive making it hard to correlate the two standards adequately;
- The Brazilian standards do not present alternatives for improvements in the environmental impact of buildings by taking into account their emission of CO_2.

The ambiguities and limitations presented by the two Brazilian thermal performance standards have a direct impact on the understanding of the designers, since the parameters addressed in both standards are not always presented in an equivalent way to be followed. The costs for requesting the standards can also represent a barrier for their use. Conversely, the lack of updates discourages the application of more recent constructive techniques and encourages the application of the standards for situations not addressed by them, such as for buildings other than residences.

For the reasons described above, the review demonstrated that the updating process of the standards is necessary to remedy gaps, answer to constructive ambiguities and to include aspects not previously addressed. Likewise, adapting advanced policies inspired by other countries with greater experience promotes a reference of efficiency and quality to the processes of improving the thermal performance of buildings in Brazil and the well-being of their users.

5.1 Recommendations for future research

Some suggestions for future works in this line of research are:

- To systematize comparisons using other limit values than U-values to analyse the envelope performance of buildings;
- To test computational simulations with the limit values of the standards, in order to obtain a comparison of their practical efficiency;
- To evaluate differences in thermal performance of buildings between Brazil and other countries with well-established standards.

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ANNEXES

A. Revocation of the building regulations over the years

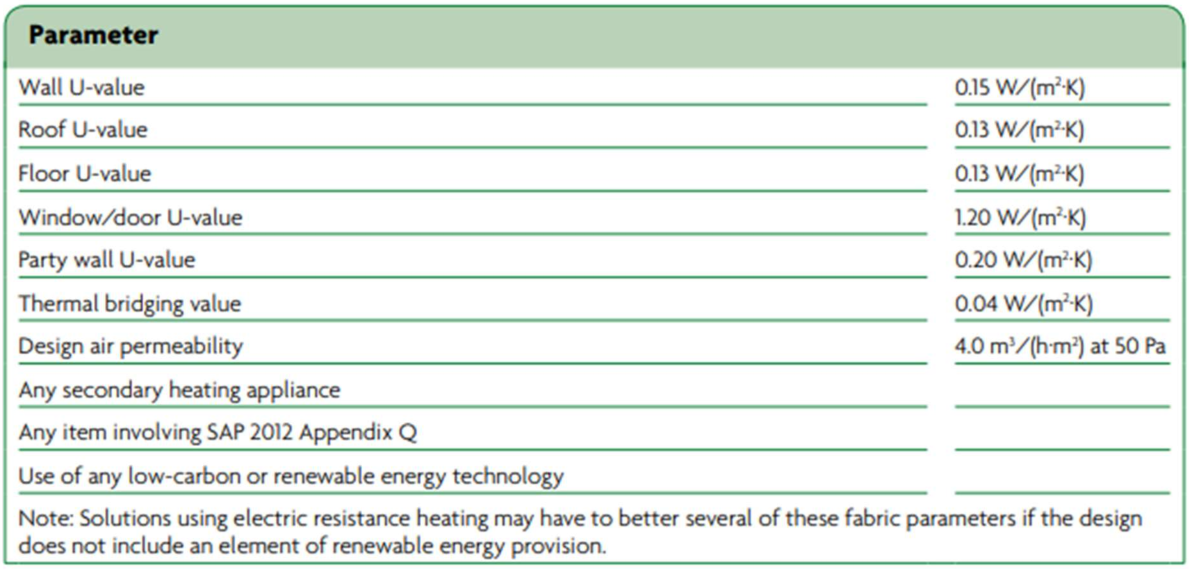
SCHEDULE 5 Regulation 54(1)

Revocation of Regulations

Regulations revoked	*References*	*Extent of revocation*
The Building Regulations 2000	S.I. 2000/2531	The whole Regulations.
The Building (Amendment) Regulations 2001	S.I. 2001/3335	Regulation 2, regulation 4 in so far as it relates to regulation 2 and the Schedule.
The Building (Amendment) Regulations 2002	S.I. 2002/440	Regulations 2 and 3 and the Schedule.
The Building (Amendment) (No. 2) Regulations 2002	S.I. 2002/2871	The whole Regulations.
The Building (Amendment) Regulations 2003	S.I. 2003/2692	The whole Regulations.
The Building and Building (Approved Inspectors etc.) (Amendment) Regulations 2003	S.I. 2003/3133	The whole Regulations.
The Building (Amendment) Regulations 2004	S.I. 2004/1465	The whole Regulations.
The Building (Amendment) (No. 3) Regulations 2004	S.I. 2004/3210	The whole Regulations.
The Building and Approved Inspectors (Amendment) Regulations 2006	S.I. 2006/652	The whole Regulations.
The Building and Approved Inspectors (Amendment) (No. 2) Regulations 2006	S.I. 2006/3318	The whole Regulations.
The Energy Performance of Buildings (Certificates and Inspections) (England and Wales) Regulations 2007	S.I. 2007/991	Schedule 2 and regulation 8.
The Building and Approved Inspectors (Amendment) Regulations 2007	S.I. 2007/3384	The whole Regulations.
The Building (Amendment) Regulations 2008	S.I. 2008/671	The whole Regulations.
The Energy Performance of Buildings (Certificates and Inspections) (England and Wales) (Amendment No. 2) Regulations 2008	S.I. 2008/2363	Regulation 3.
The Building (Amendment) Regulations 2009	S.I. 2009/466	The whole Regulations.
The Building and Approved Inspectors (Amendment) Regulations 2009	S.I. 2009/1219	The whole Regulations.
The Building (Amendment No. 2) Regulations 2009	S.I. 2009/2397	The whole Regulations.
The Building and Approved Inspectors (Amendment No. 2) Regulations 2009	S.I. 2009/2465	The whole Regulations.
The Building and Approved Inspectors (Amendment) Regulations 2010	S.I. 2010/719	The whole Regulations.

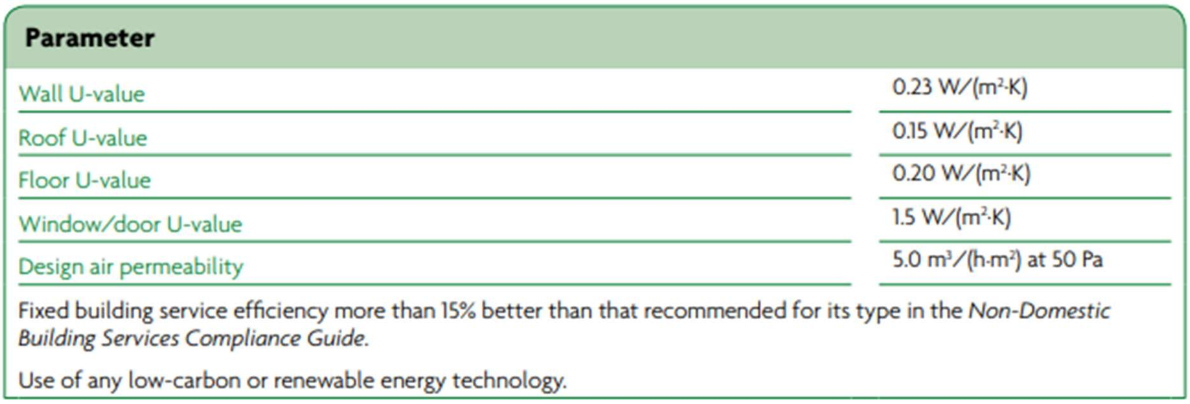
Figure 10 - The Building Regulations revocations (TSO, 2010).

B. Limiting U-values for different building systems in the building regulations



Parameter	
Wall U-value	0.15 W/(m^2·K)
Roof U-value	0.13 W/(m^2·K)
Floor U-value	0.13 W/(m^2·K)
Window/door U-value	1.20 W/(m^2·K)
Party wall U-value	0.20 W/(m^2·K)
Thermal bridging value	0.04 W/(m^2·K)
Design air permeability	4.0 m^3/(h·m^2) at 50 Pa
Any secondary heating appliance	
Any item involving SAP 2012 Appendix Q	
Use of any low-carbon or renewable energy technology	
Note: Solutions using electric resistance heating may have to better several of these fabric parameters if the design does not include an element of renewable energy provision.	

Figure 11 – U-values for dwellings – The building Regulations - Part L1A (HM GOVERNMENT, 2010)



Parameter	
Wall U-value	0.23 W/(m^2·K)
Roof U-value	0.15 W/(m^2·K)
Floor U-value	0.20 W/(m^2·K)
Window/door U-value	1.5 W/(m^2·K)
Design air permeability	5.0 m^3/(h·m^2) at 50 Pa
Fixed building service efficiency more than 15% better than that recommended for its type in the *Non-Domestic Building Services Compliance Guide*.	
Use of any low-carbon or renewable energy technology.	

Figure 12 - U-values for new buildings other than dwellings - The building Regulations - Part L2A (HM GOVERNMENT, 2013)

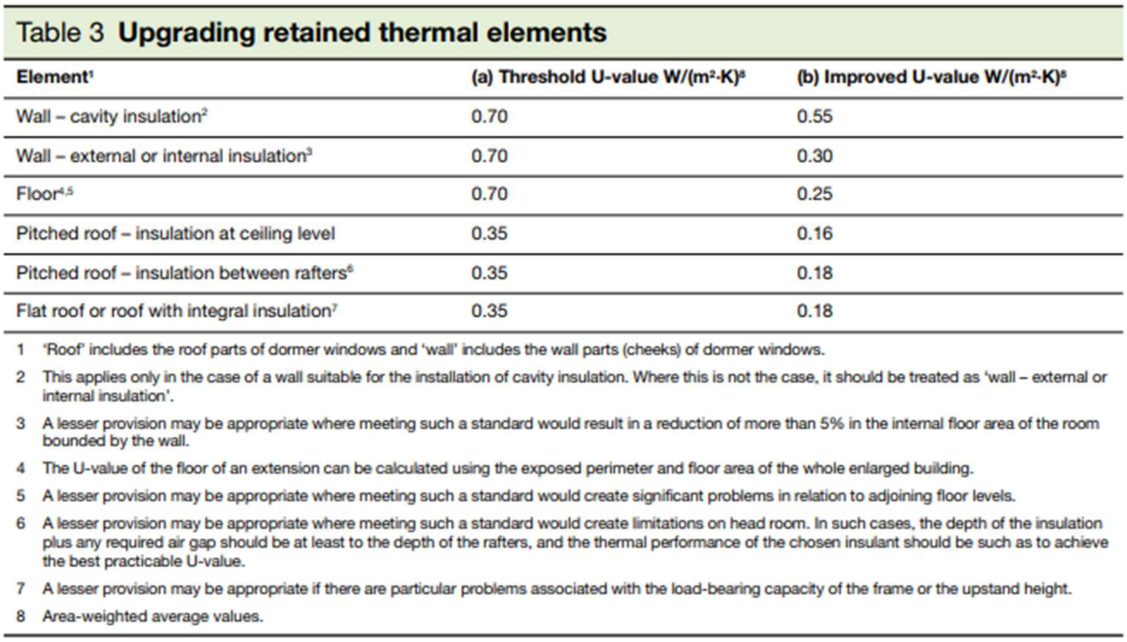


Table 3 **Upgrading retained thermal elements**

Element[1]	**(a) Threshold U-value $W/(m^2{\cdot}K)$**[8]	**(b) Improved U-value $W/(m^2{\cdot}K)$**[8]
Wall – cavity insulation[2]	0.70	0.55
Wall – external or internal insulation[3]	0.70	0.30
Floor[4,5]	0.70	0.25
Pitched roof – insulation at ceiling level	0.35	0.16
Pitched roof – insulation between rafters[6]	0.35	0.18
Flat roof or roof with integral insulation[7]	0.35	0.18

1 'Roof' includes the roof parts of dormer windows and 'wall' includes the wall parts (cheeks) of dormer windows.

2 This applies only in the case of a wall suitable for the installation of cavity insulation. Where this is not the case, it should be treated as 'wall – external or internal insulation'.

3 A lesser provision may be appropriate where meeting such a standard would result in a reduction of more than 5% in the internal floor area of the room bounded by the wall.

4 The U-value of the floor of an extension can be calculated using the exposed perimeter and floor area of the whole enlarged building.

5 A lesser provision may be appropriate where meeting such a standard would create significant problems in relation to adjoining floor levels.

6 A lesser provision may be appropriate where meeting such a standard would create limitations on head room. In such cases, the depth of the insulation plus any required air gap should be at least to the depth of the rafters, and the thermal performance of the chosen insulant should be such as to achieve the best practicable U-value.

7 A lesser provision may be appropriate if there are particular problems associated with the load-bearing capacity of the frame or the upstand height.

8 Area-weighted average values.

Figure 13 - U-values for existing dwellings - The building Regulations - Part L1B (HM GOVERNMENT, 2010)

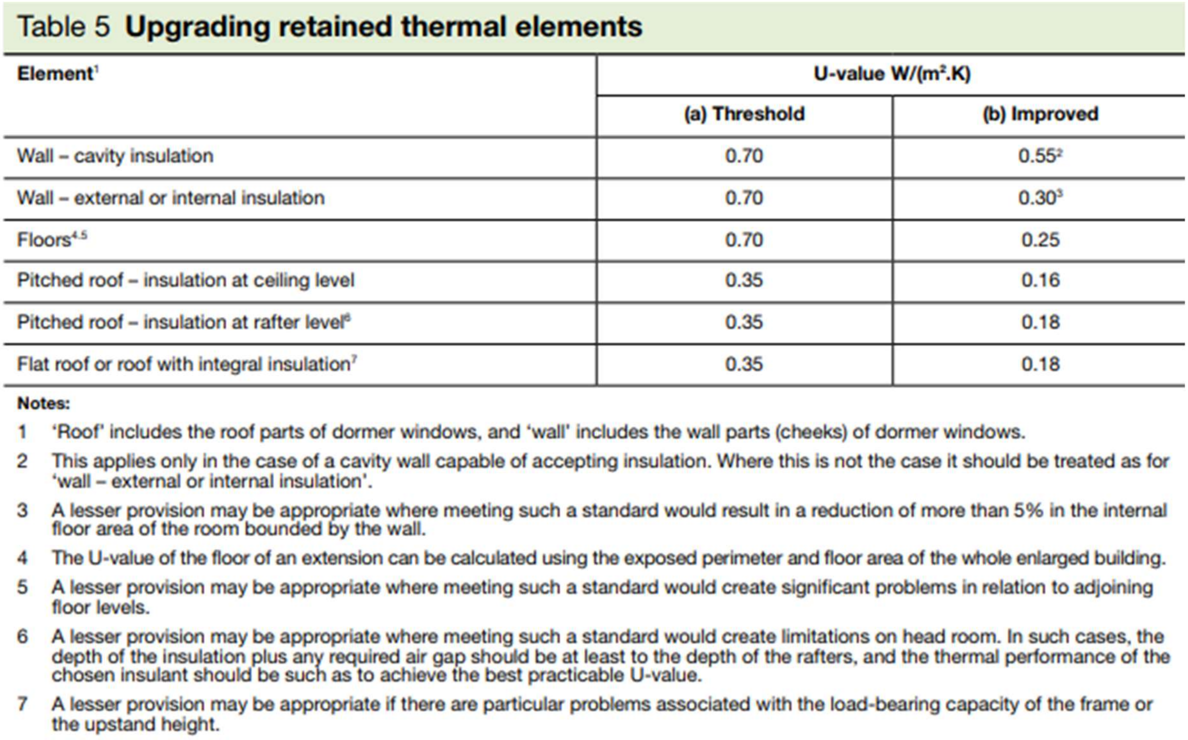


Table 5 **Upgrading retained thermal elements**

Element[1]	**U-value $W/(m^2.K)$**	
	(a) Threshold	**(b) Improved**
Wall – cavity insulation	0.70	0.55[2]
Wall – external or internal insulation	0.70	0.30[3]
Floors[4,5]	0.70	0.25
Pitched roof – insulation at ceiling level	0.35	0.16
Pitched roof – insulation at rafter level[6]	0.35	0.18
Flat roof or roof with integral insulation[7]	0.35	0.18

Notes:

1 'Roof' includes the roof parts of dormer windows, and 'wall' includes the wall parts (cheeks) of dormer windows.

2 This applies only in the case of a cavity wall capable of accepting insulation. Where this is not the case it should be treated as for 'wall – external or internal insulation'.

3 A lesser provision may be appropriate where meeting such a standard would result in a reduction of more than 5% in the internal floor area of the room bounded by the wall.

4 The U-value of the floor of an extension can be calculated using the exposed perimeter and floor area of the whole enlarged building.

5 A lesser provision may be appropriate where meeting such a standard would create significant problems in relation to adjoining floor levels.

6 A lesser provision may be appropriate where meeting such a standard would create limitations on head room. In such cases, the depth of the insulation plus any required air gap should be at least to the depth of the rafters, and the thermal performance of the chosen insulant should be such as to achieve the best practicable U-value.

7 A lesser provision may be appropriate if there are particular problems associated with the load-bearing capacity of the frame or the upstand height.

Figure 14 - U-values for existing buildings other than dwellings - The building Regulations - Part L2B (HM GOVERNMENT, 2013)

Certifico que o aluno(a): **Tacila Cristina Caetano Kingscott**, autor(a) do trabalho de conclusão de curso intitulado "**Comparative analysis of thermal performance standards for buildings between Brazil and the United Kingdom**", efetuou as correções sugeridas pela banca examinadora e que estou de acordo com a versão final do trabalho.

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Ouro Preto, 23 de dezembro de 2018.