Energy Rehabilitation of Residential Buildings: Proposed Solutions for Bragança City

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Abstract. Portugal is committed to achieving carbon neutrality by 2050, intending to comply with the Paris Agreement on climate change and global warming. Renovating existing buildings is particularly relevant for decarbonization, and the long-term renovation strategy (LTRS) defines how to achieve this goal.

In Bragança city, more than 50% of the existing buildings are recent, built after 1981, and only 6% of them consider the first regulation based on the Energy Performance of Buildings Directive. It can be concluded that there is a considerable number of buildings, built without any legislation or based on poor thermal legislation, which requires adaptations to the new requirements of thermal comfort and energy performance in the coming years.

Based on a study of the residential energy buildings characterization in the city of Bragança, this work intends to present a set of intervention proposals to improve their energy efficiency, meeting the requirements of recent national legislation on the energy performance of buildings following the LTRS Principles.

Keywords: Energy rehabilitation · Residential buildings · Portugal · Bragança

1 Introduction

Nowadays, there is a consensus in the scientific community that the progressive increase in greenhouse gas (GHG) emissions over the last 100 years has increased the planet's temperature, causing undesirable climate changes. The latest report by the Intergovernmental Panel on Climate Change predicts a global temperature rise of 2.7 degrees by 2100 if the current pace of GHG emissions is kept [1]. The Paris Agreement, adopted in 2015, set the aim of continuing efforts to limit the average increase in global temperature to 1.5 °C, recognizing that this would significantly reduce the risks and impacts of climate change [2]. For that, it will be necessary to achieve carbon neutrality in the second half of this century. In line with this, the European Commission (EC) presented, in November 2016, the Clean Energy Package to promote the energy transition in the coming decades, and Portugal, as an EC member, assumed the commitment to achieve carbon neutrality by 2050 through the approval of the Roadmap for Carbon Neutrality 2050. To precisely fulfil the objectives of decarbonization and the energy transition, the

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National Energy Climate Plan was approved (PNEC 2030), with measures for the 2030 horizon [3, 4].

Relative to buildings, PNEC 2030 sets out specific lines of action, including promoting energy renovation in the building stock. Research of EU residential building stock [5] shows that environmental impact from new buildings is negligible compared to the impact from existing buildings. The European Ecological Pact also drives renovation of buildings, with a new strategy called "A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives" [6]. These lines of action aimed at the construction sector, namely existing buildings, are essential. In Portugal, as in other countries of the European Union, buildings are responsible for about 30% of final energy consumption and 5% of GHG emissions [3]. In this sense, the Energy performance of buildings directive determines the obligation of each Member State to establish a long-term strategy to support the renovation of buildings until 2050 (LTRS) [7]. The objective will be to convert the existing building stock into decarbonized and highly energy-efficient, transforming existing buildings into Nearly Zero Energy Buildings (NZEB) [7, 8]. Financing programs and incentive policies are necessary [9] and planned to encourage this energy transformation, so dynamism is expected in the coming decades. Specifically, the measures to be taken in existing buildings included in the LTRS are: - intervention in the building envelope; - replacement existing systems; - and promotion energy from renewable sources. It should be noted that priority should be given to the building envelope [10], with a significant environmental improvement potential, which, for a majority of buildings, represents at least 20% compared to the base case [5, 11]. The variation in the thermal insulation thickness implies a great variation in the total primary energy consumption and better cost-efficient results is obtained from insulating Roofs [12]. In Portugal, most interventions in this field, as they are isolated acts, do not need a project. In this way, decisions pass to the owners and builders, with little training in the area, missing unique opportunities to improve the building stock's energy efficiency effectively.

In this sense, this study aims to present proposals for energy rehabilitation in the building envelope, meeting the identified needs. It is focused on residential buildings of Bragança city. Bragança serves as an excellent example because more than 50% of the existing buildings are recent, built after 1981. Only 6% of them consider the first regulation based on the Energy Performance of Buildings Directive [13]. It can be concluded, like in other European countries [14], that there is a considerable number of buildings, built without any legislation or based on poor thermal legislation, which requires adaptations to the new thermal comfort and energy performance requirements in the coming years.

2 Methodology

The intervention proposals presented in this study intend to follow up another study with contributions to the energy characterization of residential buildings in Bragança [13]. This characterization was based on statistical data analysis, expert interviews, and the study of 250 residential buildings, energy certified, belonging to the 1980s, 1990s and 2000s.

The intervention proposals are accompanied by tables, which summarize the characteristic solutions of the opaque building envelope (walls, floors and roofs) and windows, with the thickness of elements presented in cm. It was intended to fit the requirements of the existing buildings to current requirements. The necessary thermal insulation thickness was calculated using average market values (thermal conductivity coefficient: 0.0300.04 W/mK) to verify the maximum (U Max.) and reference (U Ref.) thermal transmission coefficients required by the current legislation, the Decree-Law 101-D/2020 [15].

The buildings are separated by different construction periods according to the evolution of the thermal legislation:

- Years of Construction: 1980–1992, buildings built without any thermal legislation (Before RCCTE).
- Years of Construction: 1993–2008, buildings built by Decree-Law nº 40/90 (RCCTE-1990) [16]. This regulation is responsible for the beginning of placing thermal insulation in the building envelope, especially in walls.
- Years of Construction: after 2008, buildings built by Decree-Law nº 80/2006, with stricter thermal requirements than RCCTE-1990 (RCCTE-2006) [17].

It is important to note that the thermal legislation was reflected in the construction approximately two years later. Beyond the evolution of legislation, the evolution of market construction was also considered. For example, only from the 2000s onwards, a better aluminium frame, with thermal break, characterizes the windows. At the beginning of this decade, PVC (polyvinyl Chloride) frame also emerged as a recurring option. The separation in two types of building – multi-family and single-family – was only made for the construction period "RCCTE-2006, after 2008" because only in this period the divergence between the two began to have an impact.

The intervention proposals presented in this study are based on the suggested improvements of energy certificates and the solutions available on the market. In addition, technical, functional, and economic aspects were analyzed.

3 Intervention Proposals

3.1 External Walls

External walls before RCCTE-2006, especially from the 1980s have a huge potential for intervention through incorporating thermal insulation, as can be seen in Table 1.

Insulation can be applied outside, inside, or into the air space. In rehabilitation, the ETICS system (External Thermal Insulation Composite Systems) is the most used system from the outside, having a lower cost than most external systems, is easier to apply, and has less impact at an aesthetic level. Despite being a solution with a higher cost, Ventilated Facades can have advantages in adding aesthetic value and not interfering with the existing coating.

Exterior insulation systems have the advantage of maintaining the building's thermal inertia and treating sensitive areas, such as pillars and beams, and linear thermal bridges

Table 1. External wall solutions

Construction age	Before RCCTE 1980-1992	RCCTE- 1990 1993-2008	RCCTE- 2006 After 2008	
External walls, solutions for construction periods				
			multi-family building	single-family building
Characteristic solution U [W/m².⁰ C]	Brick15+ Air space + Brick11 U=1	Brick15+ Air space+ XPS3+ Brick11 U=0,57	Brick15+ Air space + XPS4+ Brick11 U=0,5	Brick15+ Air space + XPS6+ Brick11 U=0,4
U Max. = U Ref.	U=0,35			
Thermal bridges, pillars,…isolated?	No	No	Yes	Yes
Isolation to achieve U Máx/Ref	6cm - 8cm	3cm - 5cm	2cm - 4cm	2cm

through the continuity of the insulation. However, an agreement condominium is necessary in multi-family buildings. When this does not happen, when it is impossible to change the aesthetics of the building, or when it is technically challenging to carry out the work, insulation from the inside (placed directly on the wall or forming a structure with an air gap) is an option. The most common thermal insulations are expanded polystyrene (EPS), extruded (XPS), cork, glass wool or rock wool. One must be selective in choosing these materials, as some incentive programs for renovating buildings are committed to environmental sustainability. It will be guaranteed through the choice of eco-materials or recycled materials.

In double walls without thermal insulation, incorporating loose insulating materials or injecting insulation foam in the air space can be presented as a solution. However, although it is an easy and economical solution, it offers fewer guarantees of insulation continuity (due to the possible existence of reduced air thickness of the debris). Single constructive elements, such as pillars and beams, are not isolated. In addition, it is a wrong solution in terms of linear losses and also poses difficulties in terms of quality control of the work.

3.2 Internal Walls

Internal wall solutions (which separate conditioned spaces from unconditioned spaces) from the 1980s and, in general, interior wall solutions in contact with garages, laundry rooms, buffer zones and attics are the ones with the greatest potential for intervention through the incorporation of thermal insulation.

Table 2 demonstrates the Internal wall solutions by the different construction periods.

Table 2. Internal wall solutions

Construction age	**Before RCCTE 1980-1992**	**RCCTE- 1990 1993-2008**	**RCCTE- 2006 After 2008**
Internal wall solutions			
Characteristic solution U [W/m².⁰ C]	**Adjacent buildings** Brick 11/15+ air space+Brick11 U=0,88 **Common zones** Brick 15 U=1,5 **Laundry/Storage/Buffer zones/Attics** Brick 11 U=1,9	**Adjacent buildings** Brick 11/15+ air space+XPS3+ Brick11 U=0,55 **Common zones** Brick 11+XPS3+ Brick11 U=0,65 **Laundry/Storage/Buffer zones/Attics** Brick 11 U=1,9	**Adjacent buildings** Brick 11/15+ air space+XPS4+ Brick11 U=0,48 **Common zones** Brick 11+XPS3+ Brick11 U=0,65 **Laundry/Storage/Buffer zones/Attics** a) Brick 15 U=1,5 (bztu ≤ 0,7) b) Brick 7+XPS4+ Brick7 U=0,58 (bztu > 0,7)
U Max. [W/m².⁰ C]	U=1,9 (bztu ≤ 0,7) U=0,35 (bztu > 0,7)		
U Ref. [W/m².⁰ C]	U= 0,6 (bztu ≤ 0,7) U= 0,35 (bztu > 0,7)		
Thermal bridges, pillars,…,isolated?	No	No	Yes
Isolation to achieve U Máx.	**Adjacent buildings** - **Common zones** 8cm-10cm (bztu > 0,7) **Laundry/Storage/Buffer zones/Attics** 8cm-10cm (bztu > 0,7)	**Adjacent buildings** - **Common zones** 4cm-6cm (bztu > 0,7) **Laundry/Storage/Buffer zones/Attics** 8cm-10cm (bztu > 0,7)	**Adjacent buildings** - **Common zones** 4cm-6cm (bztu > 0,7) **Laundry/Storage/Buffer zones/Attics** a) - b) 3cm-5cm (bztu > 0,7)
Isolation to achieve U Ref. *XPS/EPS/Mineral wool/cork (…)*	**Adjacent buildings** 2cm-3cm **Common zones** 3cm-4cm (bztu ≤ 0,7) 8cm-10cm (bztu > 0,7) **Laundry/Storage/Buffer zones/Attics** 4cm-5cm (bztu ≤ 0,7) 8cm-10cm (bztu > 0,7)	**Adjacent buildings** - **Common zones** 1cm (bztu ≤ 0,7) 4cm-6cm (bztu > 0,7) **Laundry/Storage/Buffer zones/Attics** 4cm-5cm (bztu ≤ 0,7) 8cm-10cm (bztu > 0,7)	**Adjacent buildings** - **Common zones** 1cm (bztu ≤ 0,7) 4cm-6cm (bztu > 0,7) **Laundry/Storage/Buffer zones/Attics** a) 3cm-4cm (bztu ≤ 0,7) b) 3cm-5cm (bztu > 0,7)
bztu > 0,7- spaces with temperatures close to the outside temperature: Umáx is de same as the external walls. Adjacent Builings: bztu = 0,6			

In the case of internal walls, it is not necessary to consult the condominium in most cases. The profitability of incorporating insulation will generally be more significant in these cases: -in older buildings; -with lighter or damaged coatings; -when the insulation does not reduce the useful area; - and when the contact of the non-conditioned space (like a laundry or a storage) with the outside is significant. As a rule, energy performance is better if the insulation is applied to the outside of the wall. There are prefabricated insulated solutions that are an excellent solution for interior spaces.

3.3 Floors and Roofs

According to Table 3, there is a significant energy savings potential incorporating thermal insulation in the roofs and floors of buildings before the RCCTE-2006, especially in single-family buildings where the decision is made by the owner, without intervention

Table 3. Roof and floor solutions

Construction age	Before RCCTE	RCCTE-1990	RCCTE- 2006	
	1980-1992	1993-2008	After 2008	
Roofs and Floors, Solutions			 multi-family building	 single-family building
Characteristic solution U [W/m^2.^{0} C]	**Ceilings below attics** Lightened slab 20cm U=2,25 **External Floors** Lightened slab 25cm U=2,0 **Internal Floors** Lightened slab 25cm U=1,6	**Ceilings below attics** Lightened slab 30cm U=1,87 **External Floors** Lightened slab 40cm U=1,4 **Internal Floors** Lightened slab 40cm U=1,2	**Ceilings below attics** Lightened slab 30cm + XPS 6cm U=0,46 **External Floors** Lightened slab 40cm+ XPS/Mineral wool 3cm U=0,68 **Internal Floors** Lightened slab 40cm+ XPS/Mineral wool 3cm U=0,64	**Ceilings below attics** Lightened slab 30cm + XPS 8cm U=0,37 **External Floors** Lightened slab 40cm+ XPS/Mineral wool 4cm U=0,58 **Internal Floors** Lightened slab 40cm+ XPS/Mineral wool 4cm U=0,54
U Max. [W/m^2.^{0} C]	U=1,2 (bztu $\leq$ 0,7) U= 0,3 (bztu > 0,7)			
U Ref. [W/m^2.^{0} C]	U= 0,5 (bztu $\leq$ 0,7) U= 0,3 (bztu > 0,7)			

(*continued*)

Table 3. (*continued*)

Construction age	**Before RCCTE** **1980-1992**	**RCCTE-1990** **1993-2008**	**RCCTE- 2006** **After 2008**	
			multi-family building	**single-family building**
Isolation to achieve U Máx. *XPS/EPS/ Mineral wool/cork (...)*	**Ceilings below attics** 2cm (bztu ≤ 0,7) 9cm-12cm (bztu > 0,7) **External Floors** 9cm - 12cm **Internal Floors** 1cm (bztu ≤ 0,7) 8cm-11cm (bztu > 0,7)	**Ceilings below attics** 1cm (bztu ≤ 0,7) 9cm-11cm (bztu > 0,7) **External Floors** 8cm-11cm **Internal Floors** 8cm-10cm (bztu > 0,7)	**Ceilings below attics** 3cm-5cm (bztu > 0,7) **External Floors** 5cm-8cm **Internal Floors** 5cm-7cm (bztu > 0,7)	**Ceilings below attics** 1cm-3cm (bztu > 0,7) **External Floors** 4cm-7cm **Internal Floors** 4cm-6cm (bztu > 0,7)
Isolation to achieve U Ref. *XPS/EPS/ Mineral wool/cork (...)*	**Ceilings below attics** 5cm-7cm (bztu ≤ 0,7) 9cm-12cm (bztu > 0,7) **External Floors** 9cm-12cm **Internal Floors** 5cm-6cm (bztu ≤ 0,7) 8cm-11cm (bztu > 0,7)	**Ceilings below attics** 5cm-6cm (bztu ≤ 0,7) 9cm-11cm (bztu > 0,7) **External Floors** 8cm-11cm **Internal Floors** 4cm-6cm (bztu ≤ 0,7) 8cm-10cm (bztu > 0,7)	**Ceilings below attics** 3cm-5cm (bztu > 0,7) **External Floors** 5cm-8cm **Internal Floors** 1cm (bztu ≤ 0,7) 5cm-7cm (bztu > 0,7)	**Ceilings below attics** 1cm-3cm (bztu > 0,7) **External Floors** 4cm-7cm **Internal Floors** 4cm-6cm (bztu > 0,7)

bztu > 0,7- spaces with temperatures close to the outside temperature: Umáx is de same as the external walls

by the condominium. Furthermore, in the latter case, the intervention is more uncomplicated, and as the ceiling height is usually higher, it allows more flexibility with the thickness of the floors.

In most cases, it is by insulating the non-habitable attic from the roof (preferably placing the insulation on the slab) that more significant energy savings and shorter payback times are achieved, since: - attics have temperatures very close to the outside; - the area of intervention is important; -and the measure is economical (in most cases it is enough to place only the insulating, without functional and aesthetic interferences). In addition, it must be ensured that the roofs have ventilation openings, preferably controllable (to open in summer, prevent overheating and close in winter, reducing heat losses). Choosing light colours and low emissivity coatings help to reduce summer energy needs.

3.4 Windows

As can be seen from the Table 4, the most significant potential for windows/openings intervention is mainly found in buildings from the 1980s (before the RCCTE-1990).

Table 4. Window solutions

Construction age	**Before RCCTE**	**RCCTE- 1990**		**RCCTE- 2006**
	1980-1992	**1993-2000**	**2000-2008**	**After 2008**
Windows solutions for construction periods				
Characteristic solution U [W/m².⁰ C]	Aluminum frame without thermal break, sliding, light color, single glazing 4mm Plastic exterior blinds U=4,1 (some *windows without protections: U=6,5)*	Aluminum frame without thermal break, sliding, light color, double glazing 5+8+4mm Plastic exterior blinds U=3,1 *(some windows without protections: U=4,4)*	Aluminum frame with thermal break,tilting window, light color, double glazing 5+12+4mm Plastic exterior blinds U=2,58 *(some windows without protections: U=3,5)*	PVC or Aluminum frame with thermal break,tilting window, light color, double glazing 6+16+5mm Plastic exterior blinds U=2,1/2,5 *(some windows with internal protections: U=2,7/3,3)*
U Max. = U Ref. [W/m².⁰ C]	U=2,2			

The contribution of windows depends on the frame, glass, and shading devices. In winter, they can cause significant thermal losses, and in summer, they can be responsible for internal overheating problems. In extensive renovations, changes dimensions and location of windows should be studied. Preference should be given to south-facing windows, sizing the shading devices well. The north and west windows must be minimal. When the frame is still in a good state of repair and there is space for placing another frame, the double system will provide good reinforcement of the thermal resistance. However, it may reduce the light transmissivity, be unsightly, and in summer, it may contributing to overheating because of the air gap between the windows. If the frame is in poor condition, the best solution will be its replacement, adopting solutions with better thermal performance.

As for the opening system, tilt and turn systems, in addition to having lower air permeability, allow for more effective ventilation control. One of the most important aspects to consider is the solar factor regarding glass replacement. The current double glazing, with an air gap of about 16 mm, is in most cases a good solution due to improved insulation and reduced risk of condensation. Although less economical, there are solutions with argon or low emissivity double glazing. In terms of solar protection systems, in addition to other functions (light control and privacy), they prevent spaces from overheating in summer and reinforce the window's thermal resistance. Preferably, they should be placed outside the window, with light colors as they reduce the incidence of solar radiation.

Blind boxes are sensitive to air infiltration and have a low thermal resistance. The incorporation of thermal insulation in buildings before the RCCTE-2006 provides improvements in terms of energy performance and thermal comfort. If there is space, insulation can be incorporated inside the box, resulting in a simple, quick, economic measure that does not interfere with the aesthetics of the adjacent areas.

3.5 General Considerations

Any intervention must be used to intervene and requalify thermally and energetically. Therefore, a prior technical-economic assessment of possible solutions is essential. Some of these are only viable when deep intervention is needed. It should be noted that other factors, such as thermal comfort or even the aesthetic aspect, must be considered.

Quality assurance in the application and installation of systems must be based on the proper qualification and responsibility of the installers. Likewise, certified materials guarantee the quality and durability of the systems.

Sometimes, the real solutions of the building envelope are not those considered in the energy certificate. Due to lack of information, solutions may have been considered by default, mainly in buildings corresponding to the period from 1992 to 2004. For a more specific characterization, non-destructive "in-situ" measurement tools with Thermographic Cameras and Heat Flow Sensors can be used.

4 Conclusions

The goals for the energy transition, together with the clear trend towards the rehabilitation of buildings, will undoubtedly be reflected in more demanding legislation and instruments to support energy efficiency, serving as levers to improve the energy performance of existing buildings.

In Bragança, many buildings were built without any legislation or based on a poor legislation, requiring interventions and adaptations to the new thermal and energy comfort requirements in the coming years. These buildings, before the RCCTE-2006, are essentially characterized by a reinforced concrete structure, double walls with low thermal insulation thicknesses in the air space and the absence of thermal insulation in most of the remaining constructive elements. In addition, the buildings before the RCCTE-1992 are characterized by sliding window frames systems and single glass. This type of construction provides sensitive and unique areas, causing discomfort and significant thermal losses. So, there is considerable potential for energy savings if the renovation of buildings is carried out efficiently. The reinforcement of the thermal resistance of the various constructive elements deserves special attention, namely on the roofs. It should be noted that the building envelope and passive systems should assume more importance to the detriment of technical systems.

Interventions in existing buildings are often isolated measures without a thermal project and without prior control by city councils, technicians, and specialists. However, these interventions should allow existing buildings to become NZEB buildings in the future. It is essential to provide more information, especially for owners and builders, to adopt best practices and prevent these frequent interventions from being a waste of improvement opportunities in the coming years.

References

1. Intergovernmental panel of Climatic Change, IPCC, Climatic Change 2021 (2021)
2. United Nation, Paris Agreement 2015 (2015)
3. RNC 2050, Roadmap for carbon neutrality 2050, Long-term strategy for carbon neutrality of the Portuguese economy by 2050 (2019)
4. PNEC 2030, Plano Nacional de Energia e Clima, Resolução do Conselho de Ministros n.º 53/2020, 10 julho 2020 (2020)
5. Nemry, F., et al.: Options to reduce the environmental impacts of residential buildings. In: The European Union-Potential and Costs, Energy and Buildings **42**(7), 976–984 (2010)
6. https://eur-lex.europa.eu, COM(2020) 662, A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. Access 10 Mar 2022
7. European Parliament and the Council, Directive (EU) 2018/844, amending Directive 2010/31/EU regarding the energy performance of buildings and Directive (2018)
8. ELPRE, Estratégia de Longo Prazo para a Renovação dos Edifícios, 03 de fevereiro de 2021, Resolução do Conselho de Ministros n.º 8-A/2021 (2021)
9. Zhang, H., Hewage, K., Karunathilake, H., Feng, H., Sadiq, R.: Research on policy strategies for implementing energy retrofits in the residential buildings. In: Journal of Building Engineering **43** (2021)
10. Aelenei, L., et al.: Design issues for net zero-energy buildings. In: Open House International **38**(3), 7–14 (2013)
11. Sadineni, S.B., Madala, S., Boehm, R.F.: Passive building energy savings: a review of building envelope components. In: Renewable and Sustainable Energy Reviews **15** (2011)
12. de Vasconcelos, A.B., Pinheiro, D.M., Manso, A., Cabaço, A.: EPBD cost-optimal methodology: application to the thermal rehabilitation of the building envelope of a Portuguese residential reference building. In: Energy and Buildings **111**, 12–25 (2016)
13. Fernandes S.: Contributos para a caracterização energética de edifícios habitacionais do concelho de Bragança. In: CIEEMAT, III Congresso Ibero-Americano de Empreendedorismo, Energia, Ambiente e Tecnologia, Instituto Politécnico de Bragança (2017)
14. Iralde, N. S.I., Pascual, J., Salom, J.: Energy retrofit of residential building clusters. a literature review of crossover recommended measures, policies instruments and allocated funds in Spain, Energy and Buildings **252** (2021)
15. Decreto-Lei n.° 101-D/2020, de 7 de dezembro - Estabelece os requisitos aplicáveis a edifícios para a melhoria do seu desempenho energético e regula o Sistema de Certificação Energética (2020)
16. Decreto-Lei n.° 40/90 de 6 de fevereiro, Regulamento das Características de Comportamento Térmico dos Edifícios (1990)
17. Decreto-Lei n.° 80/2006 de 04 de abril, Regulamento das Características de Comportamento Térmico dos Edifícios (2006)