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SCIENCE4POLICY

CONCURSO DE ESTUDOS DE CIÊNCIA PARA AS POLÍTICAS PÚBLICAS

ECO_ELPRE: Encouraging more environmentally sustainable options in the rehabilitation of buildings, throughout their life cycle

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Executive Summary

Analysis:

- The Long-Term Strategy for Building Renovation, adopted in 2021 and monitored until 2024, indicates that the savings achieved in carbon emissions in the sector are due to the increased use of renewable energy in the electricity grid supply, and not directly to the performance of buildings.
- Most of the interventions in buildings, supported by the Environmental Fund under ELPRE, promoted energy efficiency, and reduced the operational carbon footprint of buildings, through the renovation of components and equipment, but not through the optimization of their bioclimatic performance.
- These funded interventions did not guarantee low energy and carbon emission levels from materials, so they did not reduce the embodied carbon footprint of buildings and their materials, and did not always guarantee passive thermal comfort, indoor air quality and reduced life cycle costs.
- ECO HELPRE indicates that the renovation of components may not be sufficient to improve the sustainability of buildings and housing units and should be addressed within the framework of their integrated rehabilitation, considering comfort, habitability, energy, materials and water.

Recommendations:

- Production of a unified LCA methodological framework applicable to the rehabilitation of buildings.
- Creation of local observatories for sustainable rehabilitation.
- Green credit for housing rehabilitation.
- Training and capacity building of professionals and decision-makers in the sector.
- One-Stop Shop and building renovation passport.
- Promotion of a better articulation between the renewal of components and spatial-functional rehabilitation.
- Promotion of a better synergy between energy and water renewal of components.
- Experimentation in pilot buildings.

Recipients: Energy Agencies, Government Entities of Housing and Rehabilitation Policy

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1. Context and Background

Approximately 85% of European buildings were built before 2000 and 75% of the total have low energy performance (1).

In Portugal, the situation is similar: 80% of buildings predate 2000 (2) and 66% of buildings have an energy certification equal to, or lower than C, which reinforces the urgency **of**

renovation interventions that improve energy performance of buildings (3).

In view of the worsening impacts of climate change, particularly regarding the availability and management of water resources, the **water efficiency of buildings** is of increasing importance, but renovation interventions, supported by the public policies under analysis, have not been sufficient for an effective reduction in water consumption.

In the context of the European Green Deal, published in 2020, there is a favourable policy framework to deepen and accelerate the energy and water renovation of buildings in Portugal.

In line with European commitments for decarbonisation and energy efficiency, the Portuguese Government approved, in 2021, the Long-Term Strategy for the Renovation of Buildings (ELPRE), with the aim of guiding and monitoring the renovation of the national building stock.

The level of ambition of the Portuguese ELPRE can be considered high (4) since almost two thirds of the national building stock was built before the introduction of energy efficiency requirements for buildings, and, therefore, it is ageing, particularly in the residential sector.

ELPRE was the main national instrument to promote a sustainable renovation of buildings, making energy goals compatible with the enhancement of the built heritage (5).

However, the building sector in Portugal has been decarbonised mainly due to the transition of the energy production sector, now with a greater contribution from renewables, and not as a direct result of the actions to renovate the building stock, as shown by the ELPRE indicators (5).

Building renovation policies at European level are framed by the European Directive on the Energy Performance of Buildings (EPBD, 2024) (1), where a new indicator was proposed based on the global warming potential (GWP) expressed in Kgs of carbon equivalent emissions (CO2eq). This indicator results from the application of the environmental performance assessment method, which allows, among others, to assess carbon emission throughout the several stages from the life cycle of buildings.

Additionally, the *New European Bauhaus Compass* (6) also frames projects for the sustainability of the built environment, and at the national level the qualification is given by the Energy Certification System for Buildings (SCE), in force (3) and by the Environmental Fund Funding Programs (7).

Problems identified in the implementation of ELPRE

Since 2021, energy renovation interventions in buildings have promoted energy efficiency and have been able to reduce the **carbon footprint of buildings** (5)

> *"the global analysis of the results suggests that apparently the building sector is "decarbonizing" due to upstream changes in energy production, and it is necessary to reinforce investment in the energy rehabilitation of the existing building stock"* (*7th Progress Report - ELPRE, 2024, p.10*)

These interventions did not ensure low levels of energy and **carbon emissions embodied** in the materials, and did not always guarantee thermal comfort and indoor air quality.

Energy renovation interventions have sometimes even created unwanted effects associated with greater tightness of homes, with the emergence of humidity problems and pathologies associated with condensation, particularly when there is insufficient ventilation, resulting in **environmental discomfort**.

On the other hand, cases were identified in which, in the substitution of systems and equipment for more efficient options, the citizen (or the consumer) was not informed how to use them, having an opposite effect to that expected, increasing energy consumption and costs (see indicator 8 of .Thus,Table 1) the following problems stand out:

→ <u>Carbon footprint</u> and contribution to the increase of green house gases emissions, with its respective global warming potential;
→ <u>Energy poverty</u> in a low-income country;
→ <u>Environmental discomfort</u>, especially in housing.

The following areas of intervention should be taken into account in encouraging and evaluating building renovation measures to address these problems:

→ **passive comfort** (solutions for hygro-thermal comfort without the need for electrical equipment, allowing for an effective reduction in operational energy consumption)

→ **Life Cycle Assessment** (LCA) (which allowsthe measurement of the energy and global warming potential embodied in materials, valuing reuse solutions and construction materials with low environmental impact)

→ **water efficiency,** maximising its synergy with energy efficiency

→ **Resource sufficiency,** with incentives to change consumption patterns

→ **climate resilience,** promoting the adaptation of buildings.

2. Analysis of the energy renovation policy of buildings

This chapter presents an analysis of the renovation of buildings in Portugal, identifying: internal weaknesses of ELPRE, external technical and financial barriers; challenges; and opportunities for improvement.

The central objective of ELPRE was to make buildings more energy efficient, contributing to:

- the reduction of **energy bills** and dependence on fossil fuels;
- the improvement of **thermal comfort** and indoor environmental quality;
- the promotion of **public health** and well-being;
- the increase in **labour productivity**; and
- the mitigation of **energy poverty**.

ELPRE has proposed four packages of measures, oriented towards comfort and efficiency (5) combating energy poverty by improving thermal insulation; replacing inefficient lighting and systems; commitment to decentralised energy production using renewables; and, anticipating a greater demand for comfort on the part of future generations.

The results of ELPRE were monitored over four years (from 2020 to 2024), with its progress indicators, seven to date (8) In Table 1, the percentages in each indicator refer to its trajectory, in 2023, compared to the base value of 2018, in relation to the targets established for 2030 (9).

Despite the progress made in some areas, the impact of the measures has so far been less significant than expected (10) which points to the need to **strengthen the coordination, financing and adaptation** of the funded interventions (9).

Table 1: ELPRE Progress Indicators (8)

ELPRE PROGRESS INDICATORS	Progress compared to baseline (2018)	
Total Building Stock	2023	2030 target
1. Primary Energy Consumption	-6,5%	-11%
2. Local renewable energy production	25,5%	11%
3. Total renewable energy production	24,1%	68%
4. Reduction in CO2eq emissions	45,7%	15%
5. Area of renovated buildings	3,9%	49%
6. Percentage of buildings renovated	16,2%	69%
7. Hours of discomfort	-0,54%	26%
8. Savings on energy costs	-0,6%	29%

A potential of ELPRE´s improvement lies in presenting the national building stock in a clearer and more compreensive way (4) highlighting the need to better understand and characterise this stock.

Although an 8th ELPRE report may still be published, it is expected that this will be the last, since the EPBD will be transposed into national legislation in May 2026 and the National Plan for the Renovation of Buildings (PNRE) will replace the previous national strategy, the ELPRE.

The PNRE is currently being prepared by a working group created for this purpose, coordinated by ADENE, and which also includes the office of the Secretary of State for Energy and Housing, which is an opportunity for intersectoral integration of policies. The contents of the PNRE are not yet public.

2.1 Weaknesses in energy renovation policies for buildings

Emission reduction based on energy supply

Within the scope of ELPRE, building renovation policies were monitored considering factors external to the construction and rehabilitation of buildings, such as the decarbonization of the electricity supply. Indeed, part of the emission reductions reported by ELPRE reports do not reflect the efficiency of buildings, but rather the energy network decarbonisation (5) (indicators 1 to 4 of Table 1).

Emphasis on operational energy

The energy renovation resulting from ELPRE focused on energy needs and consumption during the operational phase of the building (heating, cooling, lighting and ventilation). This approach excludes other phases of the life cycle of buildings with an impact in terms of energy and emissions, such as the renovation work itself, which involves embodied energy in construction materials, demolition, recycling and reuse (embodied emissions can account for up to half of total emissions) Figure 1 (11).

This focus on operational energy, and equipment, is reflected in ELPRE's progress indicators and the poor performance related to building renovation (see indicators 5 to 8 of Table 1).

Figure 1: Breakdown between carbon emissions in the operational and embodied phases of buildings (World Building Sustainable Council)

Disregard of embodied energy

Many of the solutions implemented to improve energy efficiency in buildings have high CO_2 emissions in their production, transport and end of life. For example, the application of synthetic materials for the insulation of the building's thermal envelope, although it reduces operational energy, implies high energy incorporated, both in production stage, as in end of life stage (waste).

The life cycle analysis (LCA) of buildings allow to quantify the overall potential reduction in CO_2 emissions, both operational and embodied, which allows for decision-making based on more complete information. However, the absence of standardised methodologies to quantify the carbon footprint in the entire life cycle of building renovation (combining operational and embodied energy) is a weakness in relation to the objective of reducing the overall carbon intensity of buildings and their renovation.

Dissociation between energy renovation and building rehabilitation

The transformation of buildings encouraged by recent policies, within the scope of ELPRE (5)has been oriented towards the introduction of equipment and energy renovation of building components (e.g. replacement of windows or addition of insulation in the surrounding area) and not towards the integrated architectural rehabilitation of fractions or buildings.

Energy renovation works fall into the category of alteration works (11) although some of these are exempt from licensing, and in practice are not subject to the rules and principles of this regime.

There is, therefore, a dissociation between this regulatory framework and the practices of energy renovation of buildings, which do not always ensure the protection of heritage, or environmental sustainability, in the implications beyond operational energy efficiency.

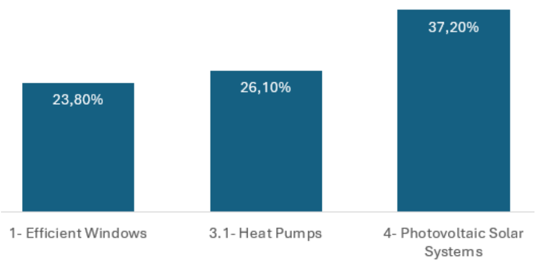
Predominance of equipment

According to data from the Environmental Fund (10) there were few applications for funding for bioclimatic and water efficiency measures (Table 2), highlighting the need to strengthen technical knowledge and environmental literacy in this area, as well as to re-orient policies towards the effective reduction of resource consumption (63.3% of the funds allocated refer to equipment).

Table 2: Distribution of the allocation of incentives from the Environmental Fund according to typology

Number of applications to the Support Programme for More Sustainable Buildings II (PAE+S II)	
Typology 1 Efficient windows	16 782 (23,8%)
Typology 2.1 Insulation in roofs and/or floors	380 (0,5%)
Typology 2.2 Wall insulation	506 (0,7%)
Typology 2.3 Entrance doors	375 (0,5%)
Typology 3.1 Heat Pumps	18 418 (26,1%)
Typology 3.2 Solar thermal systems	2 1115 (3,0%)
Typology 3.3 Biomass boilers and stoves	5 147 (7,3%)
Typology 4 Photovoltaic Solar Systems	26 197 (37,2%)
Typology 5.1 Water-efficient devices	513 (0,7%)
Typology 5.2 Intelligent water consumption systems	9 (0,0%)
Typology 5.3 Rainwater harvesting systems	0 (0,0%)
Typology 6 Bioclimatic architecture	13 (0,0%)

Figure 2: Top 3 applications by type



Little emphasis on water efficiency

There are renovation measures that result in a reduction in hot water consumption, others that reduce water consumption in general, and others that cumulatively enhance the reduction of energy consumption.

The reuse of grey water or the capture of rainwater allows the reduction of water consumption. Measures such as the insulation of hot water pipes reduce energy and water consumption. In addition, the use of efficient DHW equipment can reduce energy consumption for water heating, and water consumption itself.

Although ELPRE mentions the integration of water efficiency measures and the use of alternative water sources, water efficiency has not been a priority in the practices encouraged by the Environmental Fund, as reflected in the ELPRE indicators.

2.2 Barriers to the renovation and rehabilitation of buildings

Experience and knowledge

Limited experience in building rehabilitation, particularily with regard to energy renovation and the use of low-carbon materials, and the lack of use of tools such as life cycle assessments for rehabilitation, hinder the understanding and accounting for the mitigation of environmental impacts of interventions in existing buildings. This deficit of knowledge and technical expertise of professionals in the construction sector constitutes a barrier to a renovation/rehabilitation committed to reducing energy use and the "carbon footprint".

On the other hand, many citizens are unaware of the real benefits of low-energy and low-carbon interventions, the incentives available and the technologies best suited to their type of building.

High initial investment

Another barrier to the energy renovation of the components in buildings and their units is the initial cost of the interventions borne by the owners.

Improvements such as the addition of thermal insulation, replacement of window frames, addition of elements for shading, installation of heat pumps or solar panels imply high investments. Although energy savings materialize in the medium and long term, the lack of short-term return and the perception of financial risk can discourage owners.

In urban contexts with a high number of co-owned buildings, the lack of consensus among condominium owners on the availability of investment and on the improvements to be made aggravates the difficulty of mobilizing resources for the renovation of buildings.

Financial support after renewal

Many energy efficiency incentive programmes are based on post refund-reimbursements or subsidies . This model, although it reduces the risk of fraud, limits access to support to those who do not have their own capital to advance the investment, which excludes a large part of middle and low-income families. Furthermore, bureaucracy and lengthy reimbursement procedures discourage many potential beneficiaries (12).

Lack of technical support

The absence of an integrated vision between energy efficiency, environmental comfort and human well-being leads to partial and sometimes counterproductive solutions.

In many cases, renovations were implemented without adequate technical monitoring, which resulted in thermal comfort and indoor environamental quality (IAQ) problems. Poorly planned interventions, such as reinforcing insulation without promoting controlled ventilation, can cause condensation, mould and indoor pollutant build-up, harming the health of occupants (12).

The lack of oversight exacerbates the problem, revealing a gap between energy policy theory and its practical implementation.

2.3 Challenges for the future

Climate Resilience

Climate change puts increasing pressure on environmental comfort in buildings and the increased frequency of extreme weather events, such as heat waves, floods and storms. This new context requires a new approach to buildings, focused on their climate resilience.

Buildings must not only be energy efficient, but they must also be able to maintain comfort and safety conditions under climate stress. This implies integrating climate adaptation principles into rehabilitation, such as natural ventilation, passive shading, the use of materials resistant to thermal variations, and natural drainage (allowing water to infiltrate into the soil).

The absence of renovation policies that consider climate resilience threatens to compromise the investments made in energy efficiency and housing quality in the medium and long term.

Energy and resource sufficiency

The concept of sufficiency offers a systemic approach to the built environment. In Europe, it means, above all, "making the best use of existing buildings", considering that 25% of housing is underused and the average office occupancy rate is around 57% (13).

This approach represents a change in the patterns of resource consumption and use of buildings (12, 13), and proposes solutions which do not consume energy (14), such as limiting excessive construction areas, promoting the shared use of spaces and equipment, avoiding energy waste or enhancing a good bioclimatic performance of buildings, and their housing fractions.

The current challenge is to combine efficiency measures with sufficiency measures and renewable energy, creating buildings that, in absolute terms, require less energy to ensure comfort and functionality and can have near-zero carbon emissions.

Increased need for cooling

Global warming and intense urbanization are reversing the energy consumption profile in buildings: if historically the priority was heating, now cooling has become a central challenge, especially in southern European cities (14).

The increase in average temperature and heat waves lead to a growing adoption of active air conditioning systems, which can cancel out the gains made in energy efficiency, by creating previously non-existent consumption.

To address this scenario, it is essential to invest in passive strategies, in addition to insulation, aimed at cooling, such as shading, cross ventilation, ground cooling, solar chimneys and ventilated roofs, green roofs and high reflectance and thermal inertia materials.

Energy efficiency data

A persistent barrier to effective policy planning is the scarcity and fragmentation of data on the actual energy performance of buildings. Theoretical models or energy certifications do not reflect the actual consumption in buildings (12).

This information gap prevents the monitoring of policy impact, makes it difficult to identify priorities for intervention, and reduces investor and citizen confidence.

The future of energy renovation could benefit from the digitalisation of the sector, through interoperable databases, IoT sensors and energy management platforms capable of generating real-time information and guiding evidence-based decisions.

Thus, the collection and processing of data on actual consumption is a challenge and also an opportunity for innovation in this area.

Scales of Intervention

Resource sufficiency and climate resilience will have to be addressed at various scales, to ensure the effectiveness of measures and the well-being of communities.

Therefore, measures and incentives should consider approaches ranging from the scale of the private property, to the condominium, neighbourhood and parish, and to the municipality and intermunicipal strategies, also considering that the measures to be prioritised may not be the same throughout the national territory.

Training and Literacy

Despite the growing attention given to the energy transition, the deficit of technical and energy literacy remains one of the biggest obstacles to its effective implementation.

Flaws persist both in the training of construction professionals, who often lack skills in renovation and sustainable rehabilitation, and in the empowerment of citizens, who are unaware of the available solutions and incentives, as well as the reference framework on carbon equivalent emissions and climate mitigation and adaptation.

Overcoming these challenges will require investment in technical training, certification of skills and knowledge transfer between academia, the private sector and public administration.

2.4 Innovation opportunities

New European Bauhaus

This European initiative (6) aims to be a facilitator of the ecological transition of the built environment, contributing to a more sustainable future by taking into account the principles of sustainability, inclusion and aesthetics.

Sustainability is considered from climate objectives to the circularity of resources, the reduction of pollution and the preservation of biodiversity. Inclusion emphasises equal opportunities and universal access to affordable spaces and housing. Finally, the appreciation of aesthetics seeks to create environments that contribute to people's physical and mental well-being.

Introduction of LCA tools

The Life Cycle Assessment (LCA) (Table 5) emerges as a tool to quantify the environmental impacts associated with the various stages of a building's life, from the extraction of raw materials and construction to use, maintenance and eventual demolition or reuse. This approach makes it possible to take decisions that minimise both embodied and operational energy, and promote a more efficient use of resources.

Although the tools for assessing environmental impacts and carbon equivalent emissions in the life cycle of construction products and buildings are evolving to a common approach, they have a very high complexity and deal with a large amount of information, and can easily result in misinterpretations.

To enable the use of these tools and databases in a reliable way, the European Union and the Member States must produce quantitative emission factors of Global Warming Potential per m2, which will also require significant research work, as well as an articulation with credible databases (eg. DAPHabitat, EPD Hub)

Section 3.2 seeks to demonstrate the potential of LCA as a decision support tool in the rehabilitation of buildings to contribute to more integrated and sustainable public policies in the building rehabilitation sector. This section will focus on the initial (A1-A4) and final (C-D) phases of the life cycle of some construction products associated with energy renovation.

New Building Renovation Plans

The 2024 EPBD (1) introduced the obligation for each Member State to draw up a National Building Renovation Plan (NRP) to ensure that by 2050 the European building stock is energy efficient and fully decarbonised.

In light of the new EPBD (2024), Portugal will have to develop its own National Building Renovation Plan (PNRE), based on a common structure for Member States, and this will replace the previous national strategy, the ELPRE (as of 31 December 2026).

The PNRE is an opportunity for innovation in the energy sustainability of buildings and the resolution of the problems, weaknesses and barriers mentioned here.

The goals of the PNRE should be geared towards the appreciation of existing resources, avoiding their consumption and encouraging innovative and more sustainable construction practices.

Building Renovation Passports

The Building Renovation Passport, according to EPBD 2024, is a roadmap adapted to the thorough renovation of each building, structured in a limited number of steps that allow a significant and progressive improvement in energy performance. At the same time, it represents an opportunity to provide personalized technical support, guiding the owner in choosing the most efficient solutions from an energy and environmental point of view, aligned with the needs of the building without forgetting the European climate goals.

The Material Passport (also called Digital Product Passport) focuses on products and building systems, gathering detailed information on their characteristics, performance, circularity and environmental impact, facilitating more sustainable choices and the future reuse or recycling of these materials.

Climate adaptation

The need for climate adaptation opens up the opportunity for the rehabilitation of buildings, driving the development and adoption of innovative building solutions. Some of the policy measures and technical solutions recommended below make it possible to respond to both climate and energy demands.

3. Recommendation and exemplification of interventions

3.1 Administrative measures and technical solutions

This chapter identifies administrative measures and technical solutions that significantly reduce energy consumption, the use of materials - and the associated carbon emissions - and water waste, in the construction and rehabilitation sector, according to the state of the art (15,16) and the shared vision of the team and its consultants (see project implementation report).

As administrative measures (see Table 3), financial incentives for energy renovation, environmental certification programs and regulations that enable resource efficiency and emission reduction in the life cycle of buildings stand out.

Table 3: Administrative measures

Incentives and taxation
Tax Reductions for Proven Low-Carbon Rehabilitation*
Worsening cost of demolition waste
Subsidizing the reincorporation of components from the circular economy
Subsidizing the catalogued collection-storage of materials (material banks)
Support for technological innovation (materials and systems)
Regulation and advice
Revision of the regulations for the rehabilitation of buildings
Promotion of pre-demolition audits
Definition of mandatory minimum % of direct reuse of components in public works
Promotion of water audits (eg. Aqua+)
Public technical advice in one-stop-shops
Life-cycle emissions (GWP)*
Certification and information
Specific carbon calculator for comparative life cycle assessment (LCA) in rehabilitation*
Environmental certification (e.g. Level´s framework)
Certification of components (registration in Environmental Product Declaration - EPD)
Building renovation passports
Contractor Certification
Designer training
Energy and water consumption bills with benchmarks

**imply stabilisation of methodologies and units of carbon measurement (see summary of recommendations)*

As technical solutions (Table 4), the application of passive and bioclimatic design principles, the use of materials with low environmental impact, the integration of renewable energies and the incorporation of intelligent consumption management systems stand out.

Table 4: Technical Solutions

Energy efficiency and sufficiency
Thermal insulation of the roof (3.2)
Thermal insulation of walls (3.2)
Promotion of cross ventilation (3.3)
Shading of openings and facades (3.3)
Internal-external climate transition balconies
Efficient air conditioning equipment
Renewable energy communities
Materials and construction systems

Low Carbon Embodied Materials (3.2)
Natural –based materials (traditional and innovative)
Recycled/ reused/ local/ EPD materials
Direct reuse or recovery of components
Modular prefabrication in renovation
Water efficiency and climate resilience
Natural drainage (infiltration boxes/wells)
Rainwater collection and use
Phytopurification of greywater
Reuse of grey water (non-potable uses)
Efficient devices (flushing cisterns and sensor taps)
Smart meters (with leak detection)
Efficient domestic hot water (DHW) systems (with circulation and return)

3.2 Thermal insulation solutions

The analysis of environmental impacts in the life cycle of a product, follows the ISO 14040/14044 and EN15804 standards, is divided into modules that represent the different stages of a product (Table 5):

- A1 to A3 cover production, from the extraction of raw materials to manufacturing.
- Modules A4 and A5 refer to construction, including transportation to the construction site and construction/installation.
- B1 to B7 address the usage phase, including maintenance, repairs, replacements and energy and water consumption.
- C1 to C4 correspond to the end of life, with disassembly, transport, treatment and disposal of waste.
- D corresponds to the environmental benefits from the potential reuse or recycling of the waste generated (stage less often considered).

Table 5: LCA Modules – ISO 14040/14044 ((17)

Product Phase (A1-A3)	Construction Phase (A4-A5)	Usage phase (B1-B5)	End of Life Phase (C1-C4)
Raw Material Supply Transportation Manufacturing	Transportation Construction Installation	Use Maintenance Repair Refurbishment	Deconstruction/ demolition Transport Waste treatment Disposal
B6: Operational energy			

The analysis distinguishes between conventional insulating materials, widely used in construction in Portugal, and emerging low or negative-embodied carbon solutions, based on renewable natural resources (Figure 3).

Next, the global warming potential of various insulating materials is compared, considering only modules A1–A3 and the transport (A4) of the solutions applied in the insulation of the roof (Figure 4), and exterior walls, either from the outside (Figure 5), or from the inside (Figure 6).

Insulating materials are evaluated in terms of embodied carbon, given their growing relevance, and in scenarios that ensure the same thermal resistance, ensuring equal contribution to operational carbon.

A useful life of 50 years was considered, and the results are presented in $kgCO_2eq$. The solutions analysed include, on the one hand, the most common materials in construction in Portugal, such as XPS and ETICS systems with EPS, and, on the other hand, innovative options with natural-based materials, such as cork, hemp, straw, cotton and wool.

Ecological thermal mortars applied from the inside of the walls were also considered, suitable for situations that require the preservation of the existing façade and greater ease of execution.

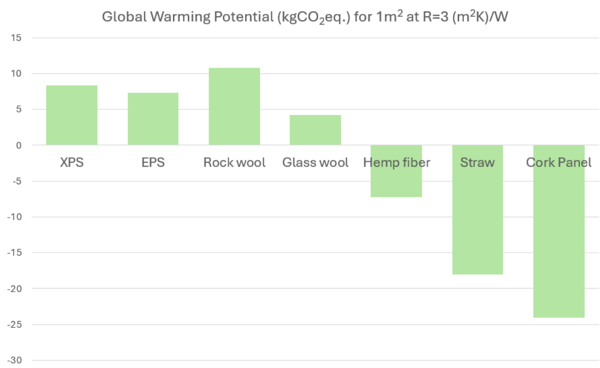


Figure 3: Comparison of insulation materials (18)

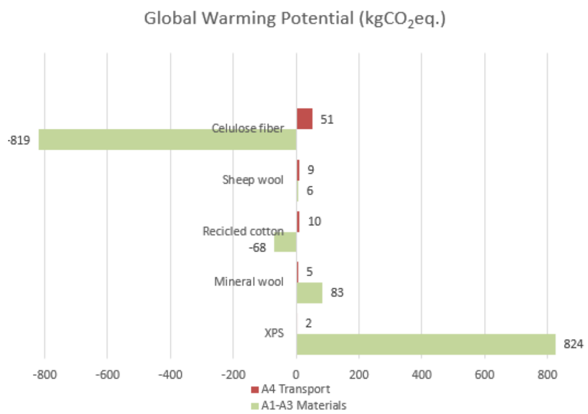


Figure 4: Roofing insulation LCA ($kgCO_2eq$)

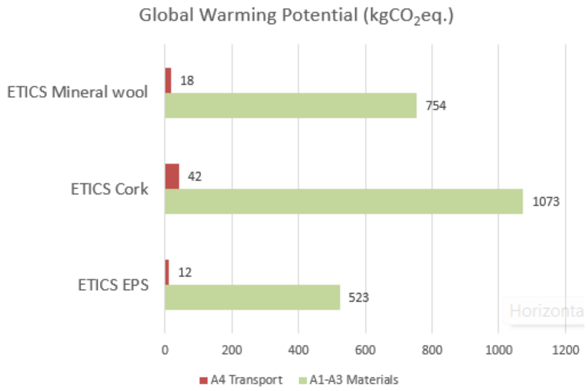


Figure 5: Wall insulation (external) LCA ($kgCO_2eq$)

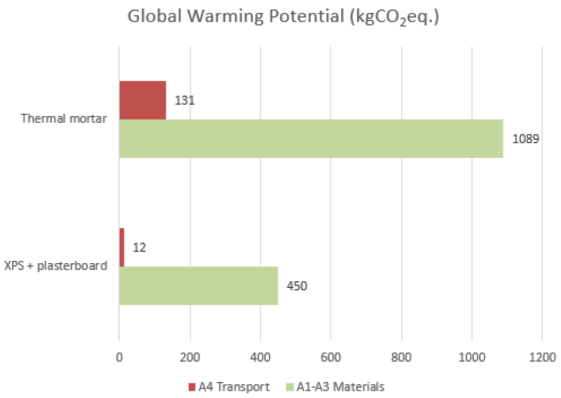


Figure 6: Wall insulation (internal) LCA ($kgCO_2eq$)

3.3 Shading and ventilation solutions

This section highlights solutions related to passive comfort that are considered economical and a priority in the face of climate change.

Following, shaded elements are illustrated (Figure 7), such as awnings or adjustable oblique blinds, on the façade (Figure 8) or vertical blinds on the balcony (Figure 9) that increase solar control and reduce energy needs for cooling.

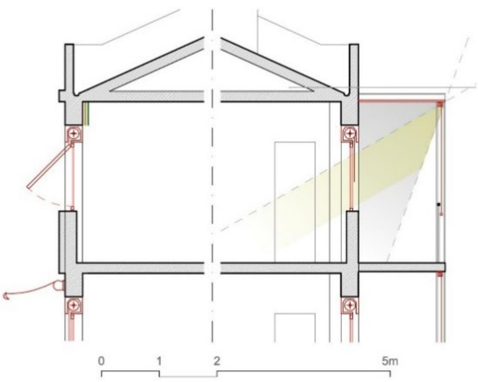


Figure 7: Cross-section of the shading solutions

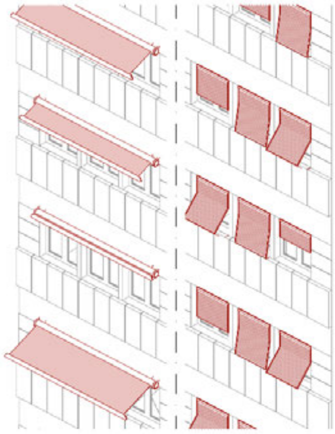


Figure 8: Adjustable blinds/awnings

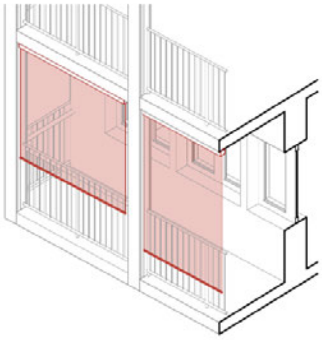


Figure 9: Vertical blinds/awnings on a balcony

In addition, simple but equally important solutions for passive cross ventilation stand out, with the introduction of ventilation grilles on the facades (in the walls or frames) (V1), or with mechanical support (V2) (Figure 10).

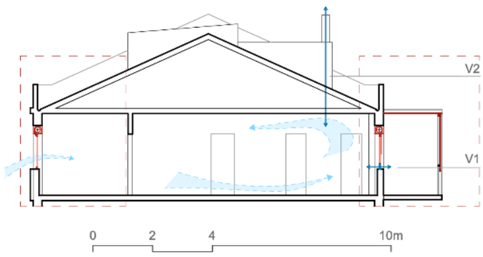


Figure 10: Ventilation solutions section

4. Recommendations

4.1 Information and communication on sustainability in building rehabilitation

Education and governance actions:

- Energy and environmental literacy programs in schools, municipalities, and local associations.

- Communication campaigns on the benefits of rehabilitating sustainable and low-carbon buildings.
- Creation of **local observatories for sustainable rehabilitation** to collect data, monitor progress, and share good practices.

Technical scope - information and literacy:

- In the technical scope, relating to the need for more information and literacy in this field, it is recommended to:
- Establish *a technical-scientific working group*, with representatives from academia, industry, professional associations, and public administration, responsible for **defining a unified Life Cycle Assessment (LCA) methodological framework applicable to building rehabilitation.**
- Ensure coordination between the new energy certification and carbon measurement systems (Global Warming Potential), stemming from the new EPBD, and aligned with the new National Building Renovation Plan (NBRP).
- Provide **training for technicians and public decision-makers** in LCA methodologies, circular economy, and energy management.

4.2 Incentives for adopting integrated technical solutions

- Establish support lines and **green credit schemes** with reduced interest rates for **housing rehabilitation** interventions that achieve carbon emission reductions.
- Promote coordination between component renewal and **spatial-functional rehabilitation**, and between **energy and water renovation.**
- Introduce complementary incentives for the circular economy, including tax benefits for those using reused, recycled, or locally sourced materials.
- Create **one-stop shops** to ensure technical support and the adoption of solutions best suited to the needs of each building or unit, guaranteeing effective and integrated energy rehabilitation in line with occupant needs and EU targets.
- Allocate incentives in accordance with the recommendations of the **Building Renovation Passports.**
- Provide support for innovation and **experimentation in pilot buildings**, allowing the testing of replicable solutions.
- Encourage energy communities to adopt rehabilitation and shared energy strategies at the local scale.

5. Conclusions

- The implementation of energy efficiency measures in building rehabilitation has primarily focused on reducing energy consumption during buildings' operational phase. However, this emphasis on operational efficiency has not ensured absolute reductions in consumption, which paradoxically continues to rise, contributing to carbon emissions and climate change.
- Public policies in Portugal should evolve towards an approach that considers the impacts associated not only with energy used for heating and cooling, but also with materials, construction processes, rehabilitation activities, and the end-of-life or reuse phases of buildings.
- For the construction sector to **better respond to climate change**, both in mitigation and adaptation, it is necessary to incorporate variables related to embodied carbon across construction, maintenance, and end-of-life or reuse stages, as well as factors related to water efficiency and energy sufficiency.
- Within the framework of the IPCC (13), sufficiency measures have been identified as a means to address excessive energy and resource consumption. When combined with renewable energy sources and energy efficiency, such measures can significantly reduce energy use and emissions.
- The growing awareness of the carbon footprint **across the entire life cycle of buildings** underscores the need for policies that integrate both operational and embodied emissions, grounded in life-cycle principles.

- The reference framework for integrating the various life cycle stages remains complex and is not yet standardised within either the European Union or Portugal.
- The simultaneous pursuit of energy renovation and architectural rehabilitation underscores the urgent need to systematise **data on the national building stock** and its typological and constructional diversity, in order to more effectively coordinate energy and water-related renovations with the spatial-functional rehabilitation of buildings and units, particularly residential ones or those adapted for this purpose.
- Optimising the use of existing buildings, a key principle of the National Building Renovation Plans (NBRP), can reduce the need for land allocation and new construction.
- The National Building Renovation Plans (NBRP) should enable the functional reuse of buildings to be combined with their energy and water renovation, leading to a real reduction in their global warming potential and the effective reuse of underutilised buildings.
- It should be noted that the recent European Affordable Housing Plan (19) states that: *"**Maximising the efficient use of the existing building stock,** avoiding unnecessary demolitions and waste, should be one of the priorities alongside the construction of new housing. This includes the renovation and repurposing of inefficient buildings, as well as the reuse of vacant properties and the regulation of short-term rentals when they compete with long-term housing."*

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