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Building Rehabilitation through nearly Zero Energy Consumption: A Case Study

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Abstract This article aims to analyse how sustainable construction creates an impact on minimizing environmental impacts and on reducing costs of conservation and operation of the buildings. It is based on a case study of a building over 100 years old which has been rehabilitated for the use of a students' residence. In the article, we present parameters that improve the sustainability of a building, such as the materials chosen, the use of clean and renewable energies, the choice of efficient materials and equipment with minimal maintenance actions needed. Two virtual scenarios are presented in order to compare costs of energy consumptions of sustainable rehabilitation towards standard rehabilitation and also to traditional rehabilitation. It is concluded that the process of sustainable rehabilitation strongly decreases energy consumption, thus reducing CO_2 emissions and decreasing the cost of building conservation. Moreover, extra costs introduced in construction to obtain extra savings in energy have got a low period of investment return, thus being advisable for general stakeholders.

Keywords: *rehabilitation of buildings, sustainability, environmental impacts, costs*

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1. Introduction

In the last decades, our country has witnessed an aging and increasing deterioration of its building heritage, particularly in urban centres, and especially in the city centre of Porto, which has reached a high degree of degradation with non-compliance for the minimum conditions of safety and comfort for its inhabitants.

Rehabilitation and sustainability complement each other as new uses are defined for the existing building, which can be expanded, improved, and converted into a more efficient and healthy space, promoting savings in energy costs, with more efficient equipment, from the water, energy, and duration perspectives. [1] Sustainable building practices are essential to protect the environment, as construction has strong environmental impacts. Implementing sustainable building practices implies pursuing a balance among economic, social, and environmental performance. [2]

After the sudden and abrupt reduction of new constructions due to the international crisis, the trend has been a progressive increase in interventions in existing constructions, by their rehabilitation. This change in the national construction paradigm encouraged the competitiveness of the companies in the sector, in the search for better results in terms of costs, deadlines and the quality of the final product. The survival and affirmation of construction companies depends, in a growing way, on their innovation capacity to respond to the problem of higher quality and lower cost [3].

Faced with this incentive to competitiveness and dealing with increasing environmental degradation, a new and better way of building, called sustainable construction, has emerged. This model defends an economic, environmental and social development, capable of meeting the needs of this generation, without compromising the needs of future generations.

Thus, this article focuses on a case study, which is the rehabilitation of a building through sustainable procedures. Initially it will be presented the design and the main characteristics of the building recently rehabilitated and, subsequently, will be analysed the constructive systems, as well as the installed equipment that are responsible for the severe reduction of carbon dioxide emissions and mitigating the impacts caused by the implementation of the rehabilitation project.

Finally will be presented results obtained from the analysis of the case study, such as energy gains, reduction of carbon dioxide emissions and cost comparisons of building operation, in order to determine how sustainable the process of rehabilitation was.

The purpose of this analysis is to compare the results obtained with other criteria of how to rehabilitate a similar building, and thus confirm that the option for energy-efficient solutions and sustainable materials enables environmental, economic and social viability throughout the life cycle of a rehabilitated building.

2. The Challenge of Sustainability in the Rehabilitation of Buildings

In Portugal, it is estimated that buildings used for housing and services are responsible, during the construction phase, for the consumption of about 20% of the national energy resources, 6.7% of general water consumption, by the production of 420 million cubic meters of wastewater and for the annual production of about 7.5 million tons of solid waste. [4]

It is of common knowledge that energy production translates into major environmental impacts because of the use and consumption of finite availability fossil fuels, such as oil and coal, and the high emission of gases resulting from consumption of these non-renewable sources.

Knowing that buildings are the main energy consumers and produce large amounts of CO_2, introducing sustainability characteristics in buildings can contribute to environmental protection. In fact, buildings account for 40% of energy usage and carbon emissions [5].This contribution can be made by applying efficient constructive systems, energy efficient equipment and several options for using eco-efficient materials.

It can also be said that the secret of old buildings rehabilitation goes through the ways of guaranteeing the sustainability of interventions, not only in the economic sense that is often given, but in a global way. Therefore, it cannot give in to the temptation to “easy and fast” rehabilitation, at the expense of the loss of meaning of the concept itself, either because it assumes the disrespect for cultural values, either because it underscores the need to guarantee buildings more capable of ensuring a compatible use with contemporary requirements.

Also for reasons that are related to the sustainability of construction, old buildings rehabilitation is today a task of the greatest importance around the world, because it is assumed as one of the paths to follow in order to achieve the goal of sustainable development of our society due to:

- Preservation of cultural values
- Environmental protection
- Economic advantages

According to Appleton, rehabilitation can be defined as the set of operations designed to ensure the possibility of full reuse of the existing building, adapting it to contemporary demands, and establishing a compromise between its original identity and resulting from rehabilitation itself. This means that, in order to talk about rehabilitation, it has to meet the knowledge and respect for the pre-existing reality of the operation, but it has to be introduced improvements in the performance of the building in several areas, from safety to comfort and also to economy. [6]

Over the years, the theme of environmental degradation has been discussed with greater strength in our society, and there is currently a need to find a solution for climate change, hoping it is not too late.

Since the Brundtland Report, there have been several agreements that identify the most important environmental problems, such as global warming. All pointed to solutions that involve the reduction of energy consumption and the development of technologies for the use of renewable energies. [7]

The last global climate change agreement was reached in Paris in December 2015 and has been validated by more than 147 countries. This agreement presents an action plan to limit global warming to a value below 2º C, which results from the emission of greenhouse gases, i.e., carbon dioxide. This agreement aims to achieve a global trajectory to be followed in order to reduce emissions of harmful gases into the atmosphere and reduce the vulnerability of societies to climate change. [7]

In our days, the construction sector is subject to several challenges: reduction and optimization in energy consumption and of water; promote the use of sustainable materials; promote the reduction of waste production (particularly construction and demolition waste); maximize the durability of buildings; and, finally, respecting nature and natural species by controlling CO_2 emissions and other gases responsible for global warming.

According to Sorrel, sustainability in old buildings rehabilitation can play a key role in protecting the environment, due to the use of constructive systems with high efficiency, [8] for example:

- Using thick thermal insulations on façades.
- Using LED bulbs in all indoor lighting.
- Replacing old domestic heating systems with high efficiency equipment.
- Using windows with double glass profiles and thermal insulation, while reducing air infiltration.
- Installing equipment that uses renewable energies, such as heating of domestic hot water through solar panels and self-production of electricity through photovoltaic solar panels for domestic consumption.

The result will be a sustainable refurbished building.

3. Methodology

This article will describe and analyse a case study. The characteristic that distinguishes this methodology is that this is a research plan that focuses on the detailed and thorough study of a single case - a one-family detached house located in the city of Porto. The methodology used aims to understand the repercussions that the sustainable rehabilitation of buildings can have in the environmental, economic and social sustainability of the building heritage, by comparison with traditional rehabilitation.

The aim of this article is to analyse the parameters that affect the sustainability of a rehabilitation of an old building. So, in this case study, it was collected real and reliable information, for comparison with other ways of rehabilitating buildings – standard and traditional.

After the survey of information about the building under analysis, the data obtained will be divided into three major themes:

- Energy consumed in heating
- Energy consumed in domestic water heating
- Energy consumed in inner lighting

For comparative purposes, two virtual rehabilitation scenarios were created (which enables the comparison of information with the case study, a building rehabilitated through sustainable constructive systems), which are:

- Standard rehabilitation – corresponding to a building similar to the case study, with standard characteristics of rehabilitation, with thermal insulation and standard efficiency equipment, defined by the Portuguese regulations.
- Traditional rehabilitation – corresponding to a building similar to the one studied without any characteristic of efficient rehabilitation, without thermal insulation or efficient equipment, only restoring the building the same way as it was before.

For a better perception of the gathered information and to understand how much the lack of sustainability affects the environment, the results of energy consumption, CO_2 emissions and annual costs of operation for the three major themes mentioned above and calculated for this case study of sustainable rehabilitation will be compared with the results for the same themes but for the two virtual scenarios – "standard rehabilitation" and "traditional rehabilitation".

4. Case Study

The sustainability of a building can be quantified through environmental, economic and social parameters. This quantification helps to improve its benefits to the user and to the environment. By using numbers, it's always possible to make things better in the future.

Through the use of data collection sources and instruments from this project, such as site visits, analysis of engineering design, consultation of the documentation of the works and access to the photographic portfolio, it was possible to collect information that allows the study of the building's sustainability. All these data enabled the following fields of research to be developed:

a. How to classify and quantify all materials used in the rehabilitation process that have a sustainable component; this classification was divided into four groups:

- Which of them were are pre-existing materials that were reused in the rehabilitation process.
- Which will be reused after deconstruction.
- Which of them will be recycled at the end of the life cycle of the building.
- Which are simply sustainable from the point of view of their constitution or their efficiency.

b. How to qualify and quantify energy needs of both electricity and natural gas, in order to subsequently compare these consumptions with the consumption of buildings rehabilitated in a standard way and also rehabilitated in the traditional way, in order to prove their sustainable characteristics, with a special focus on reducing CO_2 to the atmosphere.

Research data will be presented in this chapter in two major groups: first, the data will be presented that help to determine the sustainability of the building (environmental, economic and social parameters); second, it will be calculated the consumption of energy and carbon dioxide emissions in the case of study and, for comparative purposes, also on the two virtual scenarios created: the building similar to the one studied with standard rehabilitation characteristics and the building similar to this but without any characteristic of rehabilitation (representing the original or traditional building).

4.1. Description of the Building

The case study corresponds to a centenary building of the "single-family" house type consisting of two floors, abandoned for almost 40 years due to the lack of basic conditions for habitability, located in the city of Porto. The building was rehabilitated and it was transformed into a residence for university students, with ground floor, 1st, 2nd and 3rd floor, of type T12 (twelve bedrooms), as shown in Figure 1.

Figure 1. Building in study – Before and after rehabilitation

The rehabilitation of the building covered the reconfiguration of the interior spaces, with expansion of the façades according to the urbanistic principle of the filling of adjacent gables. In structural design, the adopted solution consisted of using the existing granite walls as support for light timber pavements, using steel profiles in the area of the pre-existing building; this structure consisted of wood and metal beams as a base for a floor made of wooden planks and ceramic tiles on top of a layer made of OSB panels. In the back of the building, corresponding to the expansion area, a reinforced concrete structure was built, with retaining walls to support the land of the backyard. The façade in granite stonework, the metal structure and wood beams are fixed to the concrete structure, working together.

The economic, environmental and social parameters that influence the sustainability of rehabilitation will be described and analysed in the following subchapters.

4.2. Sustainability Parameters Description

4.2.1. Economic Parameters

The economic analysis includes all economic parameters that are related to the high efficiency of the systems, their low energy consumption and high durability, leading to a marked decrease in the costs of operating the building. These characteristics are presented according to the following groups:

- **Use of LED bulbs** – artificial lighting is entirely by LED bulbs. 120 lamps are installed within a power ratio of $1.5W/m^2$. This ratio of LED lamps provides the same light of a ratio of $4W/m^2$ using compact fluorescent lamps and also the same light transmitted by a ratio of 12.0 W/m^2 using incandescent bulbs as in traditional dwellings.

- **Self-production of electric power** – 6 solar photovoltaic panels (PV) were installed on the roof for production of electricity for the users. The electrical equipment normally used in the daytime period are: routers, personal computers and LED lamps, in a total of 1,355 W/h. The maximum production of the 6 PV panels is 1,500 W/h, i.e. daytime power consumption is covered by the installed solar System (1,500 W/h ≥ 1,355 W/h). As the photovoltaic system allows producing electricity for self-consumption and responds to the daily's energy needs, it is only necessary to consume electricity to respond to the remaining appliances.
- **Production of domestic hot water** – a solar system was installed with four flat panels, mounted on the roof of the building, facing south. Inside the building is an accumulator of 750 litres, connected to a condensation mural boiler powered by natural gas. Domestic water heating is made, preferably, from solar energy; only in the unavailability of the solar system the heating of the water is made through the natural gas boiler. The set of solar collectors produces 5,929.00 KW per year, according to the values described in the energy certificate.
- **Low maintenance costs** - The choice of construction materials using materials, paints and finishes with high durability means that the building requires maintenance actions less often than a traditional housing. Table 1 shows the maintenance actions necessary for the proper functioning of the case study:

Table 1. Maintenance actions of the case study

Action of maintenance	Periodicity of the action (years)
Exterior Iron Painting	3
Exterior Wood Painting	3
Painting of ceilings and walls	10
Varnish on Floors	10
Thermal solar Collector	0.5
Photovoltaic Solar System	1
Changing bulbs	5

- **Efficient thermal insulation** – Heating of the interior spaces is ensured by a boiler, powered by natural gas, with hot water distribution to all radiators installed in the useable areas of the building. Since the exterior and interior enveloping was protected with thick thermal insulation, this results in the reduction of the heating requirements of the environment of 27.5% in relation to the regulatory limit, according to the information described in the energy certificate, with the consequent decrease in the consumption of fossil energy.

4.2.2. Environmental Parameters

Environmental analysis aggregates the parameters included in the decision making in the feasibility phase, with the objective of mitigating the environmental impacts associated with the rehabilitation of the building. These measures are intended to save resources – water, energy and raw materials, and reduce waste. The environmental parameters that aim to achieve the sustainability of the case study are as follows:

- **Separation of materials after deconstruction** – this analysis consisted of quantifying the various materials resulting from the future deconstruction of the building, which will be separated for recycling or for reuse in new constructions.
- The quantities of materials, as well as their percentages in relation to the overall volume of demolition, constitute an analytical mechanism in the management of the building's life cycle. These data relating to the case study are presented in Table 2:

Table 2. Deconstruction materials - Quantities and Percentages

Destination of material	Material	Tons	Percentage
Reuse	Granite Masonry	70	42.9
	Interior Woods	2	1.2
	Tiles	16	9.8
	Iron Grids	0.8	0.5
	Hydraulic Tiles	14	8.6
Recycling	Wood Structure	36	22.1
	Glass	0.4	0.2
	Ceramic Products	24	14.7
	Total	163.2	100.00

The total quantity of deconstructed work is 163.2 tons, and 63% correspond to reusable materials and 37% to recyclable materials.

- **Using sustainable materials** – Using recyclable and sustainable materials in the rehabilitation of the case study, results in a significant reduction of the energy incorporated in the construction [9].
The following types of sustainable materials were used in rehabilitation: materials of renewable origin (such as pigmented lime); working materials with solar energy (such as thermal solar panels); incorporated low-energy materials (such as rock wool); high energy-efficient materials (such as LED bulbs) and recyclable materials (exterior glazing).
Referring to the quantities of materials and components present in the construction project, it was possible to determine the approximate tons of sustainable and recyclable materials used in the construction, described in the following table:

Table 3. Materials with sustainable characteristics used in rehabilitation

Type of material	Material	Tons	Percentage
Sustainable	OSB	15.9	5.68
	Wood	13.0	4.64
	Cork	0.4	0.14
	Solar Panels	0.6	0.21
	LED lighting	0.2	0.01
	Extruded polystyrene	0.4	0.01
Sustainable and Recyclable	Structural Steel	23.9	8.54
	Rockwool	0.6	0.21
	Glazing	1.8	0.64
	Copper Wires	0.2	0.01
	Aluminium	1.2	0.43
	Plasterboard	2.0	0.71
	Subtotal of sustainable and recycling	60.2	21.53
Reusable materials	Table 2	102.8	36.71
Non-sustainable		117.0	41.78
	Total of building construction	280.0	100.00

Knowing that the estimated total quantities of building construction are of approximately 280 tons, the reusable materials represent most of the construction products used, with 36.71% of the total tons. The use of materials with sustainable and recyclable characteristics represents 21.53% of the total tons of the construction. The sum of the tons of sustainable, recyclable and reusable materials corresponds to 58.24% of the total tons of the building.

The provenance of the materials was also taken into account, that is, there was a preference in the use of local materials. The distance covered by construction materials, from the manufacturing site to the study case, was on average 24 km.

- **Indoor air quality** – Indoor air quality is ensured through a natural ventilation system, covering the entire building, so as to allow the use of pressure differences due to wind action between the various facades. The inlet air goes through by the self-regulating permanent ventilation grids, installed on top of the windows of bedrooms. The extraction of air occurs in individual bathrooms, through vertical pipes that are located at the level of the upper part of the premises and that extend to the roof and to the atmosphere. Wind fans were installed on the roof which work with air currents causing it to move and promote the suction of the hot air mass generated in the internal environment. Ideally, air admission should be located in main compartments and air extraction in service compartments, thus avoiding the propagation of bad smells through the interior of the housing.
- **Acoustic and thermal comfort of the interior** – a set of isolations and materials were studied in the design to provide the spaces for excellent insulation regarding acoustic and thermal comfort. All vertical structural elements, both exterior and interior, as well as horizontal structural elements were isolated.

4.2.3. Social Parameters

The parameters and cultural sustainability can be translated into comfort, safety and health of users. The case study presents the following social parameters that were considered in the design phase with the aim of improving the life of the building users:

- **Design of the interior spaces** – wide, coated with materials of natural origin – with use considered for this group of users, which provide a high social well-being and allows receiving friends in these cosy spaces.
- **Design of the outdoor spaces** – winter patio and summer street-refreshing spaces that encourages contact with nature. The winter courtyard in a building has the power to soften the inner temperature, in addition to bringing visual comfort. The vegetation outside a building, in addition to functioning as soundproofing, can also significantly alter the temperature of the walls and consequently, the interior of the building. These exterior spaces encourage users to have contact with green spaces and the environment.
- **Use of different colours in the finishes of the rooms** provides an increase of comfort and interaction, which allows exploring our ideas or developing an activity that pleases the user.
- **Use of differentiated construction materials in the case of rehabilitation or expansion** – gives emphasis and relevance to the rehabilitated construction. The various materials and constructive techniques used increase the architectural value of the building.
- **Design of the façade** – provides a relevance to construction far superior to neighbouring buildings, which can make the building a point of attraction.

4.3. Results

Considering that the rehabilitation of the building focused on energy-efficient systems or equipment with low environmental impact, it is important to analyse the energy consumption according to these three areas: [8]

a) Energy consumed in heating.
b) Energy consumption for heating domestic water, including the use of solar energy.
c) Energy consumption for indoor lighting using photovoltaic solar panels.

The purpose of this analysis is to demonstrate, by comparing different scenarios, the decrease in energy consumption after the rehabilitation of the building, for each of the three situations described above. We calculated, through the "Calculation sheet for evaluation of thermal behaviour and energy performance of buildings, according to the REH (Decree-Law No. 118/2013)", [10] two virtual scenarios of buildings similar to the case study, in order to compare results and prove the sustainability of the case study, which are as follows:

1. Standard rehabilitation - with thermal insulation and equipment with standard efficiencies, defined by REH [10].
2. Traditional rehabilitation - no thermal insulation nor efficient equipment, as it is common in traditional rehabilitation.

This analysis intends to confront the results obtained (energy consumption, building operation costs and CO_2 emissions) with different ways of rehabilitating a building.

4.3.1. Energy Consumption in Heating

For the analysis of energy consumed in heating, it is necessary to describe the bases for calculating the two virtual scenarios described for comparison with the case study. The criteria used in the spreadsheet were as follows:

1. Traditional rehabilitation:
   a. Useable areas without thermal insulation and with the insulation values provided in the technical standard tables;
   b. Use of standard insulation and a mural boiler with the standard efficiency equal to 0.87.
2. Standard rehabilitation:
   a. Useable areas with standard insulation values defined by regulations;
   b. Use of a mural boiler with the standard efficiency described in the regulation, equal to 0.89.

3. Case Study:
   a. Use of thicker thermal insulations;
   b. Use of a natural gas condensation boiler, with efficiency of 1.076.

The following data compare the annual consumption of natural gas in the three rehabilitation scenarios, resulting from the conjugation of the annual heating requirements with the efficiencies of the systems considered for each case.

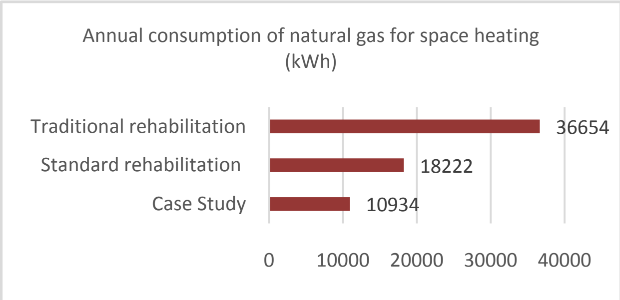

Figure 2. Annual natural gas consumptions for heating

Analysing the data from Figure 2, it is possible to observe that the annual consumption of natural gas for heating inner spaces in our case study is 70% lower than the annual consumption of natural gas for traditional rehabilitation and 40% less than the standard rehabilitation.

4.3.2. Energy Consumption in Domestic Water Heating

Considering the number of users of the case study and the average consumption of hot water, which is 560 litres per day, we calculated the energy consumed for heating domestic water. The criteria used was as follows:

1. Traditional rehabilitation:
   a. The production of solar thermal energy is not considered;
   b. Use of an heating system of domestic waters through an electric thermo-accumulator with efficiency of 0.86.
2. Standard rehabilitation:
   a. Solar panels are considered according to standard criteria of 7.5 m²;
   b. Use of a mural boiler with the standard efficiency equal to 0.89.
3. Case Study:
   Use of four solar panels with 10.0 m² of absorption area and a natural gas condensation boiler with an efficiency of 1.076.

The following figure describes the annual consumption for domestic water heating for the three scenarios under analysis:

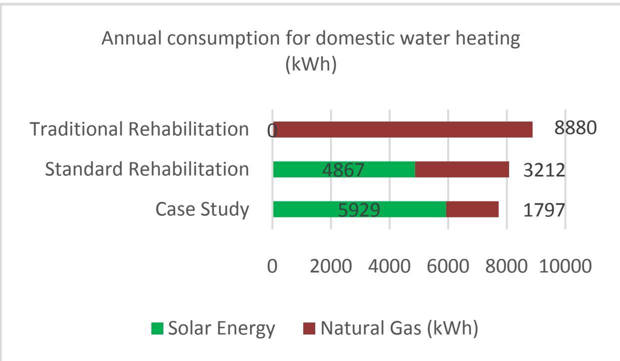

Figure 3. Annual consumption of domestic water heating

Analysing the figure data it is possible to see that our case study consumes less 80% of non-renewable energy for heating of domestic waters than traditional rehabilitation and less 44% than standard rehabilitation.

4.3.3. Energy Consumption in Lighting

For the simulation of traditional rehabilitation, it was considered that a lighting system with traditional lamps with a power of 12 W/m² would be installed. The standard rehabilitation would use an efficient lighting system based on compact fluorescent lamps with a consumption of 4 W/m². The values for the case study were obtained according to the equipment installed in the building, with the average lighting power of 1.5 W/m^2.

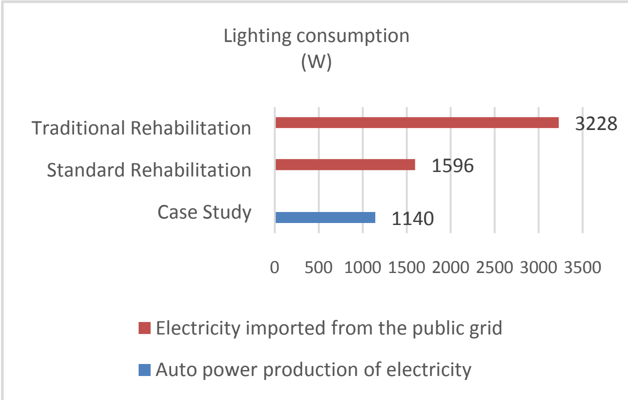

Figure 4. Lighting consumption per hour

Observing the figure, the case study consumes less 65% energy than traditional rehabilitation and less 29% than standard rehabilitation.

4.3.4. Operating Costs of Heating

Using nominal annual requirements of energy for heating in kWh (available in the energy certificate), the cost of energy and the efficiency ratio of the equipment, the costs for heating our case study per year were calculated as follows:

$$11,767\ kWh\ /\ 1.076\ (boiler\ efficiency)$$
$$x0.0537€ / kWh\ x\ 1.23\ (VAT)$$
$$= 722.30€\ per\ year.$$

As in the previous chapter, two rehabilitation scenarios were created for the same building, standard and traditional rehabilitation, in order to compare the annual costs of heating the environment.

The following table shows the annual costs of heating the environment for the three rehabilitation scenarios:

Table 4. Annual costs for space heating

	Case study	Standard	Traditional
Equipment	Boiler (efficiency 1.076)	Boiler (efficiency 0.89)	Electric heating
Source of energy	Natural gas	Natural gas	Electricity
Annual cost	722.30€	2,237.56€	6,801.80€

The cost of heating inner spaces in our case study is 309% lower than the heating in the standard rehabilitation and 941% less than the traditional rehabilitation.

4.3.5. Operating Costs of Domestic Water Heating

The total quantity of energy produced from renewable sources for the production of domestic hot water and which, according to the energy certificate, is equal to 5,929 kWh per year. The total energy needs of DHW is of 7,726 kWh, so the remaining 1,797 kWh per year will be supplied using natural gas. Taking into account the kWh of natural gas costs €0.0537 + VAT (Source: Supplier table costs) and that the efficiency of the boiler is 1.076, the annual cost of natural gas for complement of AQS is:

$$1,797\ kWh / 1.076\ (boiler\ efficiency)$$
$$x\ 0.0537€ / kWh\ x\ 1.23(VAT)$$
$$= 110.30€\ per\ year.$$

As in the previous chapters, the rehabilitation scenarios created in order to compare the annual costs of domestic water heating were the same as in previous calculations. In our case study there are thick thermal insulations and very efficient equipment, in standard rehabilitation there are standard thermal insulations and efficient equipment, while in traditional rehabilitation there is no thermal insulation and no efficient equipment.

The following table contains the annual costs of domestic hot water for the various types of rehabilitation:

Table 5. Annual costs for domestic water heating

	Case Study	Standard	Traditional
Equipment	Boiler (efficiency 1.076)	Boiler (effic. 0.89)	Water Heater (effic. 0.86)
Energy source	Natural gas	Natural gas	Electricity
Annual Cost	110.30€	394.34 €	1,716.89€

In the previous table it is possible to observe that the cost of heating domestic waters for our case study is 357% lower than the standard rehabilitation and 1556% less than he traditional construction.

4.3.6. Operation Costs in Lighting

As in the simulation performed in the chapter 4.3.3., the annual lighting costs for each scenario were quantified, taking into account that the kWh of electricity costs €0.135 + VAT (Source: supplier table costs).

The annual lighting costs were calculated using the following formula:

(W/m^2 x usable area/1000 x cost of kWh + VAT) x 12 hours x 365 days = €/year

The following table contains the annual lighting costs for each type of rehabilitation:

Table 6. Annual lighting costs

	Case Study	Standard	Traditional
Energy source	Self-production of electricity	Electricity from network distribution	Electricity from network distribution
Power per m^2	1.5	4.0	12.0
Annual Cost	0.00€	1,160.77€	3,482.31€

It is noteworthy that the annual lighting cost for the study case (daytime lighting and work equipment) is equal to zero. This is due to the self-production of electricity in the building, which responds in full to the energy needs during the day, so it is not needed electricity from the network, allowing immediate savings.

4.3.7. Costs of Maintenance Procedures

Next, we will compare information on the maintenance actions of the case study, a sustainable building, with actions to maintain a building of traditional construction. Data were obtained through specialized tools. Since the different maintenance actions have different periodicities, the costs have been reduced to annual basis.

The following table shows the costs associated with the maintenance actions necessary for the proper functioning of the sustainable building under analysis.

Table 7. Case Study maintenance costs

Maintenance Procedure	Periodicity of Maintenance (Years)	Cost of Procedure (€/year)
Painting exterior iron framework	3	450.13
Exterior Wood Painting	3	1,028.43
Varnish on floors	10	167.83
Painting of ceilings and walls	10	116.37
Thermal solar collector	0.5	358.84
Photovoltaic Solar System	1	160.28
Bulbs replacement	5	159.60
Total	-	2,441.48

Through the previous table it was possible to quantify the annual cost of operation of the case study, which is of 2.441,48 € / year.

The following table contains the costs associated with maintenance actions for the proper functioning of the building, if it was built using traditional methods. [11]

Table 8. Maintenance costs for traditional construction

Maintenance Procedure	Periodicity of Maintenance (Years)	Cost of Procedure (€/year)
Painting exterior iron framework	3	450.13
Exterior Wood Painting	3	1,467.43
Varnish on floors	3	559.42
Interior walls and ceilings painting	10	159.47
Painting of exterior walls	5	303.49
Roof	12	248.46
Traditional bulbs replacement	1	420.00
Frames	5	233.78
Total	-	3,852.18

If the building was built using traditional methods, it would have an annual operating cost of 3,852.18€ (2,441.48€ in the case study).

Assuming the life cycle of the case study is of 40 years, the cost of operation of the sustainable building will be of 97,659.20, while if the building was built through traditional methods, its operating cost would be of 154,087.20€ in 40 years.

4.3.8. CO_2 Emissions by Type of Consumption

Using the same three scenarios as a form of comparison, we will now analyse CO_2 emissions resulting from heating, domestic hot water and lighting. [12]

The data presented in Figure 5 for annual CO_2 emissions due to heating and domestic hot water are a result of annual energy consumption values in kWh shown in Figure 2 and Figure 3, multiplied by a factor of 0.202 kg of CO_2/kWh, in accordance with the legal provisions (DGEG). [13] CO_2 emissions for lighting used in traditional and standard rehabilitation consumptions are multiplied by a factor of 0.144 kg of CO_2/kWh, due to the lamps being powered by electricity. Since the lighting consumption unit is hourly, calculations have been made for average daily consumption of 12 hours of artificial illumination during the year.

In Figure 5, annual CO_2 emissions for our case study for lighting are equal to zero. This is due to the fact that solar PV panels cover the daytime energy needs of indoor lighting (1500W/h $\geq$ 1355w/h), resulting in zero CO_2 emissions in this type of consumption.

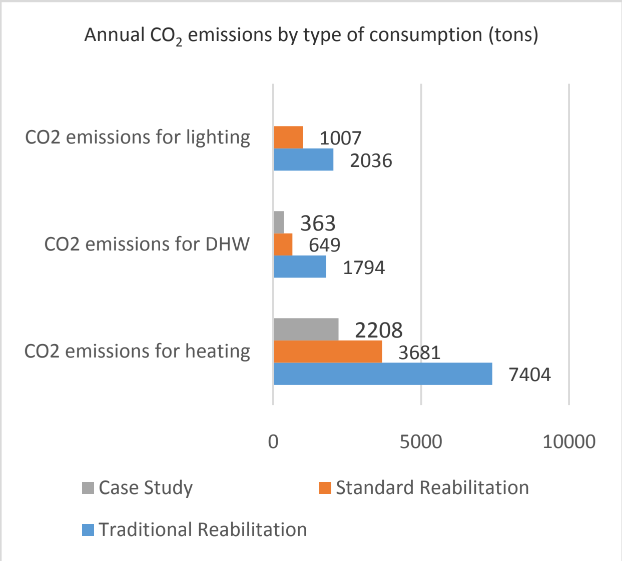

Figure 5. Annual emissions of CO_2 by type of consumption

Finally, by adding the different CO_2 emissions, the total emission results for heating, domestic hot water and lighting for each type of rehabilitation scenario are presented in Figure 6.

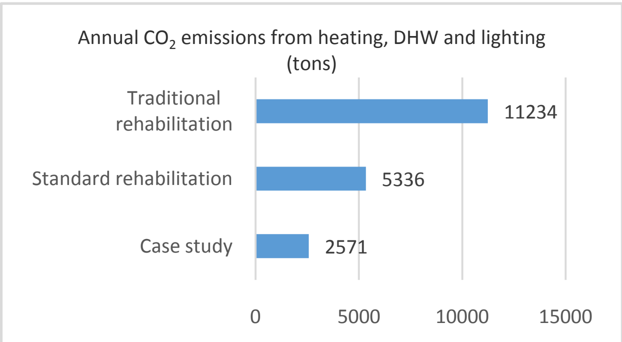

Figure 6. Annual CO2 emissions

Analysing the results obtained for the three rehabilitation scenarios of the same building, the sustainable construction of our case study emits less 77% of CO_2 than traditional rehabilitation and less than 51% that rehabilitation, which very much contributes to the sustainability of our building.

4.3.9. Financial Return by Type of Consumption

While greater investment is needed, compared to traditional construction, sustainable construction generates lower operating costs, leading not only to the a quicker financial return of initial investment, such as economy and efficiency during lifetime of a sustainable building. The challenge is to analyse costs in a balanced perspective throughout the lifecycle and not only think about the cost of the initial investment.

The best way to determine the economic profitability of the sustainable rehabilitation process is to calculate the return period of the investment. This calculation consists in determining the extra costs resulting from the introduction of sustainability characteristics in rehabilitation, as well as finding how much annual savings we can obtain in energy and maintenance using sustainable construction. With this data it is possible to determine the number of years needed for the savings to be equivalent to the investment, given that, from that point, all the savings reverting exclusively to the users of the housing with no costs. [3]

The table summarising the savings described in subchapter 4.3 is presented below (Table 9), whose data are described in the energy certificate of the building, and which are summarized in the following ideas:

1) Energy consumption for heating - The investment for reduction the consumption of energy in heating consists in using very efficient thermal insulations in the construction. The sum of the outer area of the building (cover and façades) is 566.80 m². It is considered that the extra cost for thermal insulation between our case study and standard rehabilitation is of €3.00/m², while the extra cost for thermal insulation between our case study and traditional rehabilitation is more than €9.00/m².
   The investment for reduction the consumption of energy in heating is also due to the placement of very efficient double glazing in the housing frames. The sum of the areas of the windows is 59.30 m². The added value in efficiency in relation to a rehabilitation according to the standard thickness of the double glazing doesn't cost a single euro, since the double glass with a 16mm air box has the same cost as a double glass with 6 mm of air-box, while the added value of double glazing efficiency in relation to a simple glass of traditional construction translates to a cost of more than €35.00/m².
   It also necessary to provide the construction with a condensation boiler, as previously described. The added value in efficiency in relation to a boiler according to the minimum requirements means a cost of more than €800.00, while the added value of efficiency in relation to a second-hand boiler means a cost of more than €1,700.00.
2) Energy consumption for heating domestic waters - The investment to obtain solar energy for DHW means that we must use high performance solar collectors, as well as high capacity accumulator, with thermal insulation of 100 mm and double serpentine. It is considered that the extra cost for buying this kind of equipment according to standard rehabilitation is of €1,420.00 and the added value of cost for a traditional construction is €6,500.00.

3) Energy consumption in electricity - The investment for the installation of the photovoltaic solar system was €4,500.00, so this cost is the extra cost both in relation to standard rehabilitation, as in relation to traditional rehabilitation, since none of them provides for the self-production of electricity.

So, it is possible to present, in the following table, by type of consumption, the overall value of the extra investment (EI) both in relation to standard rehabilitation and in relation to traditional rehabilitation. The columns named ACD show the decrease in annual costs for each of the situations and, in the last column (RPI), in green, the number of years until the savings match the investment.

Table 9. Return period of investment

	Standard rehabilitation			Traditional rehabilitation		
	EI (€)	ACD (€)	RPI (years)	EI (€)	ACD (€)	RPI years)
Central heating	2,500.40	1,515.26	1.6	8,876.70	6,079.50	1.5
DHW	1,420.00	284.00	5.0	6,500.00	1,606.5	4.0
Lighting	4,500.00	1,160.77	3.9	4,500.00	3,482.31	1.3
	8,420.40	2,960.40	2.8	19,876.70	11,168.40	1.8

Caption:
EI – Extra Investment in sustainable materials or equipment (€)
ACD – Annual cost decrease (€)
RPI – Return Period of Investment (years).

The financial return period of investment for the sustainable rehabilitation of the case study is 2.8 years, compared to standard rehabilitation and 1.8 years by comparison with traditional rehabilitation.

Results show that the return period is low, and provides a strong reduction in consumption, as well as emissions, during the life cycle of the construction.

5. Conclusions

We intend, with this article, to highlight the importance of sustainable rehabilitation in the panorama of the construction sector in Portugal. By sensitizing all stakeholders in the act of constructing, to obtain a reflected and sustainable construction, sustainable development is encouraged, allowing a closer future to improve the quality of life, solving current problems such as the unbridled consumption of fossil fuels and natural resources, the inescapable climatic changes associated with these facts and the high levels of environmental pollution.

Through a practical case study, we analysed the various parameters that influence the sustainability of a building, such as the materials used and their correct management, the use of clean and renewable energies, the choice by systems / efficient materials and with minimal maintenance actions needed, and also efficient insulations. This analysis aimed to prove, through this study, that the implementation of sustainable measures in a construction work can lead to environmental, economic and social benefits.

The main conclusions drawn from this work are as follows:

- Proper management of the use of deconstruction products prevents the use of new materials, thus reducing the energy incorporated in the rehabilitation of the building. In the case of a study, after the end of the life cycle, it is foreseen the deconstruction of 163.2 tons, and 63% correspond to reusable materials and 37% of recyclable materials;
- Materials with sustainable characteristics constitute 21.5% of the total tons of rehabilitation. Adding to this value the percentage of reusable materials after deconstruction, 36.7%, shows that most of the materials used in building rehabilitation are environment friendly;
- The efficiency of the equipment and the correct insulations results in lower costs associated with the operation of the building. The case study has less 309% of costs associated with heating the environment, compared to standard rehabilitation and less 941% compared to traditional construction. In relation to the AQS, the case study has annual costs 357% lower compared to standard rehabilitation and 1556% lower compared to traditional construction;
- With the preference for heating of domestic waters through solar energy (77%), only 23% of the DHW are fed by natural gas, resulting in reduced costs, which is due to the fact that solar energy is free;
- Considering energy consumption of the public network – electricity and natural gas – for heating, domestic hot water and lighting, rehabilitation through sustainable methods emits less 77% $_{CO2}$ compared to traditional construction and 51% Less than standard rehabilitation.
- The option for durable materials results in lower maintenance costs compared to traditional rehabilitation. Annually, the maintenance of the case study costs €2,441.48, in contrast to the 3.852,18€/year of traditional maintenance

While greater investment is needed, compared to traditional construction, sustainable construction generates lower operating costs, leading not only to the rapid financial return of initial investment, such as economy and efficiency during lifetime of a sustainable building.

Analysing the results for the return period of investment of equipment for central heating, DHW and lighting, for this case study, we can see that each one of them is below the 5-year limit. This short period means that these investments are very profitable, because after the five-year period has elapsed, the equipment acquisition costs are paid and the building running costs are very low.

References

[1] E. Qualharini, L. Oscar, and M. Silva, "Rehabilitation of buildings as an alternative to sustainability in Brazilian constructions". Open Engineering, vol. 9, no. 1, pp. 139-143, 2019.

[2] P. Akadiri, E.Chinvio, and P. Olomolaiy, "Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector". Buildings, vol.2, no. 2, pp. 126-152, 2012.

[3] N. Leskinen, J. Vimpari and S. Junnila, "A Review of the Impact of Green Building Certification on the Cash Flows and Values of Commercial Properties." Sustainability 2020, 12, 2729.

[4] R. Mateus, and L. Bragança, Avaliação da Sustentabilidade da Construção: desenvolvimento de uma metodologia para a avaliação da sustentabilidade de soluções construtivas. Congresso sobre construção sustentável. Leça da Palmeira, Ordem dos Engenheiros, 2004.

[5] IEA. Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector; 2018 Global Status Report. World Green Building Council: London, UK, 2018. Available: https://www.worldgbc.org/news-media/2018-global-status-report-towards-zero-emission-efficient-and-resilient-buildings-and.

[6] J. Appleton, Reabilitação de edifícios antigos – patologias e técnicas de intervenção. Amadora: Orion Editions, ISBN 972-8620-03-9, 2009.

[7] J. Coimbra, "Engineering students' perceptions of sustainability in the rehabilitation of buildings: a case study". PEOPLE: International Journal of Social Sciences, vol.3, no.2, 2017, pp. 133-154. ISSN 2454-5899.

[8] S. Sorrel, "Reducing energy demand: A review of issues, challenges and approaches. Renewable and Sustainable Energy Reviews". Elsevier, edition 47, pp. 74-82, 2015.

[9] M. Calkins. Materials for Sustainable Sites. United States: John Wiley & Sons, Inc., Hoboken, New Jersey, 2009.

[10] REH, Regulamento dos Edifícios de Habitação. Decreto-Lei nº 118/2013 de 20 de agosto. Portugal, 2013.

[11] F. Torgal, and S. Jalali, Toxicidade de materiais de construção: uma questão incontornável na construção sustentável. Associação Nacional de Tecnologia do Ambiente Construído, 2010. Available: file:///C:/Users/35191/Downloads/Toxicidade_de_materiais_de_construcao_uma_questao_.pdf.

[12] F. MacKenzie, Energy Efficiency in New and Existing Buildings: Comparative costs and CO2 savings (FB 26), Routledge, London, United Kingdom, 2011.

[13] DGEG, Direção-Geral da Energia e Geologia. Despacho nº 15793-D / 2013 de 3 de dezembro. Portugal, 2013. Available: https://dre.pt/web/guest/pesquisa/-/search/2975217/details/normal?jp=true.