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Using cost-benefit analysis for the appraisal of the building renovation projects: the case of the students' Residence Eng.º Duarte Pacheco (Lisbon, Portugal)

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ABSTRACT

In the last decades the building construction had a major expansion in Portugal. The impacts (socio-economic and ecological) of this building rush are well identified having often dramatic consequences on the whole landscape structure. Many of these impacts are also common in building renovations.
Currently there are several solutions aimed to decrease the environmental impact associated with construction and maintenance of buildings. However, their implementation is still restricted. The adoption of sustainable solutions in different stages of the building construction would be facilitated if their socio-economic and environmental benefits are quantified in such a way that both promoters and clients are used with.
Since cost-benefit analysis allows framing all the benefits and all the cost, once converted in money units, in a same analytical procedure we test for its use in evaluating the implementation of a set solutions which are thought to be environmentally friend. The renovation of the Eng.° Duarte Pacheco students' residence, in Lisbon, was used as a case study. The solutions to be implemented in the building renovation were identified using LiderA (Portuguese National Framework for Recognition of Sustainable Construction).
From our analysis, and making the current situation as reference, it was concluded that the implementation of the solutions altogether would lead to a reduction of 66% in the energy consumption and 32% in the water consumption. Also makes possible to produce the totality of energy consumed using wind and photovoltaic energy. These solutions present a payback time of 16 years at a discount rate of 5% and 13 years at a discount rate of 2%.

Keywords

Sustainable Construction; Economic Valuation; Environmental Performance; Cost/Benefit Analysis

1 Introduction

Human activities, including building construction, have impact on the environment by reducing the capacity of the supporting ecosystems to supply goods and services and by diminishing as well the capacity of these ecosystems to assimilate wastes and, generically, to absorb the induced impacts.

Because of these recognised impacts there have been several attempts to defining models and strategies for development that strive to establish the balance between the environment, society and the economy. Nowadays the sustainable development represents one of the biggest challenges for Humanity. Sustainable development was defined in the Brundtland Report [1] as ≪(...) the development that meets the needs of the present without compromising the ability of future generations to meet their own needs ≫. This concept of development guarantees the possibility to present and future generations achieve, with equity, a reasonable level of social and economical development and make a better use of natural resources without destroying the environment.

1.1 Sustainability in the Building Sector

The building sector has gradually followed, over the last decades, the population growth and the humans' aspiration for a better quality of life. As a result this sector has a strong impact in the three dimensions of sustainable development.

The building construction process comprises the following principal phases: project, construction, operation and demolition, which represents the life cycle of a building. During this time, the activities and impacts associated with the building construction vary. Generally the economic impacts linked with the buildings are wealth and employment creation, the increase in transportation demands, changes in the local traffic and pressure over the urban services. The social impacts are the creation of buildings for different utilities, problems for the local communities, safety risks and health problems. Concerning to environmental impacts there are the consumption of the natural resources, the soil occupancy, ecological changes of landscape and environmental loads [2]. For the impacts associated with natural resources consumption (water and energy consumption) and environmental loads (waste water, greenhouse gases emissions and waste) it's pressure is felt over the entire life cycle of the building, especially during the operation phase. As the performance of the buildings decreases with time, if no effort is made to minimise those impacts the effects tend to increase.

Achieving sustainability standards in the building sector represents an important challenge for the all the agents (promoters, customers, governments) involved and is still an emergent issue. On the First International Conference on Sustainable Construction, held in Tampa, in 1994 Charles Kibert defines sustainable construction as ≪(...) the creation and responsible management of a healthy built environment based on resource efficient and ecological principles ≫ [3]. Although the several definitions for the same concept [4] there is a common goal: looking for a better quality of life without compromising the environment. This new approach in the construction is aimed to minimise the building pressure over the natural resources, as well as to improve the indoor environment of the buildings (better acoustic and thermal conditions, indoor air quality and illumination). In the wide sense this concept can be understood as building practices which strive for social, environment and economic performance.

In the last decade, all over the world, it has appeared several tools to evaluate the environmental performance of buildings [5]. Examples come from the United Kingdom with the Building Research Establishment Environmental Assessment Method (BREEAM), from Japan with the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE). The tools for evaluating the environmental performance of buildings have the common goal of recognising sustainable construction by assessing the buildings performance upon the implementation of more sustainable practices and solutions.

In Portugal it also is being developed a system to support and evaluate the sustainable construction. This system, known as LiderA, is based in the concept of re-positioning the environment in construction, in the perspective of sustainability. LiderA is said as an evaluating system to lead for the environment [6].

Taking into account the Portuguese reality, LiderA has the purpose to evaluate the environmental performance of the buildings. This framework intends to be an important tool for recognition of sustainability in the building sector able to distinguish the environmental performance and socio-economic performance of the buildings.

With LiderA, the classification process of the buildings is made through levels of performance which must show if the solutions adopted are sustainable or not. The levels division is range from G (less efficient) and A (more efficient). The best level of performance, level A, considers a 50% reduction in comparison with the current practices (status quo) which is classified as level E. The recognition can be made from level C to A. In order to distinguish buildings with even high levels of performance, beyond level A exists more two levels, A+ associated to a improvement factor of 4 and A++ associated to a improvement factor of 10.

This system suggests a set of rules meant to identify solutions which greatly improve the performance of the building. The rules are divided into 6 categories (Figure 1) that comprise different areas of intervention, and for each area of intervention there are several evaluation criteria (in total there are 50 criteria). The criteria consider that the legal requirements are fulfilled and that they are the minimum requisites in the areas were they intervene. By applying the rules and procedures mentioned the performance of the buildings can be increased making it more environment friendly, integrated in the local communities, with better levels of comfort and can help with choosing solutions that are economic viable.

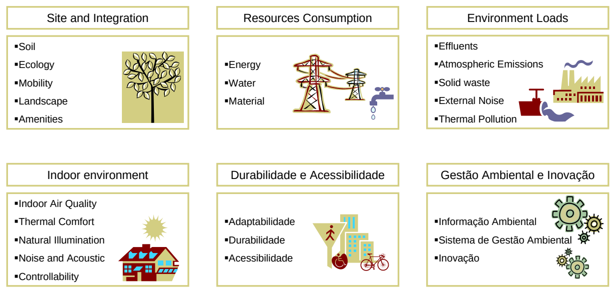

Figure 1: Categories and areas of evaluation criteria defined by LiderA.

The aim of this paper is to identify a set of solutions (from which a positive environmental impact is expected) for the renovation of students residence Eng.° Duarte Pacheco, of Instituto Superior Técnico (IST), in Lisbon. Cost-benefit analysis was used as a decision-making tool concerning its implementation.

2 Methodology

2.1 Solutions Identification

The solutions to apply in the Residences' renovation were identified with support of LiderA. For each criteria defined by the system it was proposed a set of solutions that ca be implemented on the case study. For start the solutions were identified through the current knowledge of their effect on improvement the environmental and social performances of the Residence. The search for those solutions followed the best practices and technologies in the construction industry.

Once defined the set of solutions to be used in the renovation of the building the costs and benefits of their implementation were evaluated. Our analysis is restricted to those solutions aimed to reduce the water and energy consumption and increase the thermal comfort. The choice was mainly guided by information availability. The viability of its implementation was evaluated through cost-benefit analysis.

2.2 Cost-Benefit Analysis

The cost-benefit analysis (CBA) is a technique designed to evaluate the viability of a project. Once identified the impacts associated with the project, i.e., their costs and benefits, they are quantified in monetary terms [7]. The success of this analysis relies on the identification of all project impacts that will affect human well-being as well as the quality of the impacts quantification. Many of these impacts, namely the environmental impacts do not have a price and thus its value assessment is the first challenge to cost-benefit analysis [8].

The costs and benefits evaluated through CBA are the social costs and the social benefits. They incorporate the sum of all the costs and benefits associated with a project. The costs/benefits within the project (with reflection on the organisation's production function) are called private cost or benefit. And those costs/benefits external to the project are called external costs or benefits [7]. The quantification process values the impacts in the same unit (monetary) so the social benefits can be compared with social costs. The project is feasible, for the time horizon considered, if the social benefits exceed the social costs [9].

The externality concept is particularly useful in the understanding and quantification of costs and benefits. An externality occurs when an agent (economic agent, individual, firm) affects the well-being of third parties. Externalities can be either positive, when an external benefit is generated, or negative, when an external cost is imposed to others. Often though, the occurrence of externalities is not followed by compensation or penalisation mechanisms for the agents involved [10].

The quantification process of environmental impacts in monetary units is not always straightforward. Despite its complexity there are several methods developed for such purpose (see Boardman at al., 2001 for an overview of such methods [7]).

When the information is insufficient to measure all the impacts associated with a project the externalities estimation is restricted to those whose information and methodology exist. For example, the ones that the monetary value can be obtained directly or indirectly in the market places. However, sustainability principles require the consideration of all costs and benefits, in order to avoid future restrains on using the natural resources [11]. The externalities must be quantified in monetary values, otherwise, this quantification must be held through non-monetary indicators [12].

The net present value (NPV) determines the difference between the present value of benefits and costs over some period of time (see Equation 1). It uses the discount rate as a mechanism whereby benefits and costs that occur at different points of time can be compared and weighted. For this purpose two preconditions are required. First the variables of the analysis have to be put into common unit. And second is the comprehension that we value a unit of present cost or benefit more highly than a unit of cost or benefit in the future [13].

$$NPV(s) = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} \tag{1}$$

where,
B_t = benefit in year t;
C_t = cost in year t;

n = number of years of the time horizon;
t = present year;
r = discount rate.

The economic viability of a project is assessed through cost-benefit analysis by using the following expression [14],

$$\sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} > 0 \tag{2}$$

The results obtained can also be compared by the benefit-cost ratio (B/C) [13],

$$B/C = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}} \tag{3}$$

Between the values measured by the equations 2 and 3 there are the following relationships:

$$\begin{cases} NPV > 0 \text{ then } B/C > 1 \\ NPV < 0 \text{ then } B/C < 1 \\ NPV = 0 \text{ then } B/C = 1 \end{cases}$$

In economic analysis the NPV is the measure used to evaluate the viability of a project. The economic objective is to maximise this value [13]. When $NPV > 0$ the project is feasible because benefits are higher then costs [12].

At the end of the analysis the solutions were aggregated and the performance of the students' residence after the solutions implementation was classified according to LiderA.

3 Case Study

In this work, as mentioned before, the analysis performed were focused on the Eng.° Duarte Pacheco students residence which belongs to Instituto Superior Técnico (IST). This building was selected because of the author's familiarity with the building and because of the availability of relevant information for the analysis we present in this article. Furthermore, due to the large amount of residents the energy and water consumption is significant and any improvement that might rise from implementing the presented solutions will have impact on the lives of many students. The case study selection also allows to promote environmental, social and economical efficient technologies within the student community, which in turn might lead to more environmental friendly lifestyles.

3.1 Description

The IST's Eng.° Duarte Pacheco students residence is located between Moscavide and Parque das Nações (Figure 2). It was built in 1997, which at the date of writing corresponds to 10 years of existence. The building was first used as tourist housing during the 1998 World Exhibit, after which it was converted to the Eng.° Duarte Pacheco students residence and currently houses 220 students.

The recorded information can be summarised into two categories: data regarding the Residence and the opinion of the students that live there. The Residence data consists of electricity and water consumptions, with an average annual consumption of 446MWh/ano and 17 400m^3/ano respectively, and the building areas information (Table 1).

For the purpose of collecting the opinion of the residents', a questionnaire was elaborated to obtain data regarding water and electricity consumption habits; thermal and acoustical comfort conditions of the bedrooms; management of produced residues and about the student's mobility. The enquiry (66) showed that for the residents the major problem with the building is the low thermal comfort level provided. In the summer time the bedrooms and the kitchens are hot or very hot, while in the winter time the bedrooms are moderately cold or cold and the kitchens are cold. This dissatisfaction

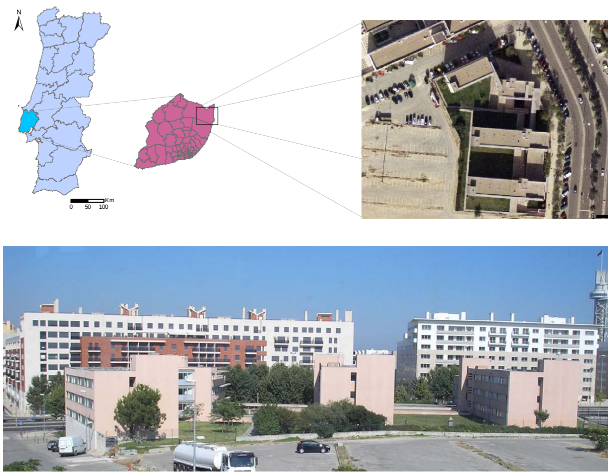

Figure 2: Students Residence Localization.

Table 1: Dados of the Residence of Students (referring to the year of 2004).

Electricity Consumption	
Annual Average Consumption (kWh/year)	445 935
Annual Average Cost (€/year)	51 090
Water Consumption	
Annual Average Consumption (m^3/year)	17 376
Annual Average Cost (€/year)	21 845
Main Areas	
Total Area (m^2)	6 746
Interior Area (m^2)	5 119
Exterior Area (m^2)	1 628
Roof Area (m^2)	1075
Window Area (m^2)	500
Terrace Area (m^2)	347

is expressed by a usage of heating and cooling equipments that has a direct influence on the energy consumption, 61% of the residents recur to fans on the hot months and 53% use heaters on the cold months. Regarding the acoustic comfort, 40% of the enquired students claim to be disturbed by exterior noises. Finally, the enquiry also identified the lack of selection garbage habits with nearly half of the students declare themselves as being not engaged in residue separation.

4 Results

Within the type of solutions proposed on the context of LiderA system there is a broad range of possible solutions for implementation. However, due to the of lack of information needed to determinate the costs and benefits associated with the solutions implementation, in the present study, the solutions evaluation was restricted to those which economical viability could be assessed.

Based on data collected about the building and on the results of the questionnaires, the study focus on the solutions with the greatest benefits once implemented. The solutions that intervene on the resources level, more precisely, on the energy efficiency and on the water consumption reduction have a fundamental importance towards increasing the Residences' environment performance. So, as shown in Table 2, were identified solutions to reduce the primary energy consumption (double glazing, outdoor window blinds, efficient electric equipment, efficient light bulbs and solar collectors), renewable energy sources usage (wind and photovoltaic power) and to reduce the necessary water consumption for domestic usage (flow and flush reducers).

4.1 Reference Situation

The considered alternatives for studying the economic viability of the solutions where based on the current state of the Residence. In this regard, the evaluation was made accordingly to the reference situation for which the environmental performance is to be improved. Table 3 describes for each intervention level the reference conditions and the options to be undertaken.

4.2 Benefits and Costs Quantification

In order to quantify the impacts associated with energy consumption (externalities) it was used the results of a European study were Portugal was part of, the ExternE project [15]. This study estimated the externalities caused by different energy process for electricity production. For the impacts associated with domestic water consumption it was considered the hydro resources rate (TRH) stated on *Lei Quadro da Água* [16].

Before proceeding to the costs and benefits quantification, the energy and water consumptions were disaggregated by kind of uses (see tables 4 and 5). This disaggregation followed two studies: for those solutions that minimise energy consumption it was used the *Matriz Energética de Lisboa* and those applied to minimise the water consumption used the *Matriz da Água de Lisboa* [17, 18].

Table 4: Desegregation of Residence electricity consumption by kind of use.

Domestic Use	Consumption (kWh/year)	Cost (€/year)
Electric DHW	107 024	12 261
Domestic cold	80 268	9 196
Indoor heating	75 809	8 685
Meal preparation	71 349	8 174
Illumination	44 593	5 109
Mechanical wash	26 756	3 065
Others	40 134	4 598
TOTAL	**445 934**	**51 089**

Table 5: Residence domestic capitation and water consumption by kind of use.

Domestic Consumption	152 L/hab/day	%
TOTAL	**17 376 m^3**	**100%**
Residents	12 206 m^3	70%
Garden	5 170 m^3	30%

Domestic Use (residents)	Consumption (m^3/year)	Cost (€/year)
Showers	5 981	7 519
Flushing	2 685	3 375
Faucets	2 563	3 222
Washing machines	732	920
Others	244	306

On the present analysis the cost of the solutions identified does not include the installation costs due to the lack

Table 2: Sustainable solutions to be included in cost-benefit analysis proceeding.

Global Benefits	Specific Benefits	Sustainable Solutions	Site	Area/Quantities	Justification
Energy and air pollution (greenhouse gases)	Primary energy reduction	Double glass	Window area	500 m^2	Total window area - it was considered the correspondent area of rooms, kitchens and the existent corridor in block C.
		Outdoor Blinds	Window area	500 m^2	Total window area - it was considered the correspondent area of rooms, kitchens and the existent corridor in block C.
		Efficient equipments	Kitchens and laundry room	45	The equipments that have energy efficiency information are: refrigerator, freezer, stove, washing machine and drying machine.
		Efficient light bulbs	Every place with artificial light	800	Kitchens, corridors, rooms and common areas.
	Renewable energy sources (CO_2 emissions reduction)	Solar collectors (domestic hot water)	Roofs	165 m^2	Total area occupation (considering other sources of renewable energy) - the solar collectors implementation depends on the solar radiation. The roofs appear as the best choice.
		Wind power energy	Roofs	90 m^2	Appropriate area for the implementation of vertical axis wind turbines (considering other sources of renewable energy).
		Photovoltaic energy	Roofs and outdoor south wall	700 m^2	Total area occupation (considering other sources of renewable energy) - the solar panels have to be implemented were there is a maxim solar radiation. The roofs and the external south wall appear as the best choice.
Water	Domestic water reduction	Flush reducers	Flush tanks	195	Working at this level it is possible to reduce the domestic water consumption.
		Flow reducers	Faucets and showerheads	408	Working at this level it is possible to reduce the domestic water consumption.

Table 3: Reference situation and considered alternatives.

Intervention	Reference	Hypotheses
Window glass	*Standard* double glazing - without solar protection	Replace by high solar protection double glazing
Solar protection	Indoor curtains	Implementation of outdoor blinds
Equipment	Class E equipment	Replace by class A equipment
Illumination	Class E light bulbs	Replace by class A light bulbs (80% electricity reduction)
Domestic hot water	Use of electricity for domestic hot water	Implementation of solar collectors for domestic hot water
Energy production	There is no energy production	Wind power and photovoltaic energy production
Flush tank	Flush tanks with a discharge of 9L	Implementation of flush reducers
Faucets and showers	Faucets and showers witch do not save water	Implementation of water flow reducers in faucets and showers

of information about this matter. For this reason it was only assumed the unitary acquisition cost obtained in the market suppliers.

In this work the social cost corresponds to the investment cost. Its determination considered the acquisition cost and the solutions implementation characteristics (area, quantity or produced energy). Depending on the solutions specification the investment cost was calculated using the following expression:

$$CI = C_{unit.} \times Q \tag{4}$$

were,
CI = investment cost;
$C_{unit.}$ = unitary cost;
Q = quantity.

Regarding to the social benefit its quantification was based on comparing the situation before (reference situation) and after the implementation of the solutions under evaluation. The social benefit was divided in private and external benefit. Benefits associated with the reduction of electricity and water bills are referred as private benefits and the benefits associated with externality minimisation represent the external benefits.

As mentioned before, the private benefit was calculated based on energy and water reduction after the implementation of the selected solutions. Formally:

$$B_P = PR \times CustoT \tag{5}$$

were,
B_P = private benefit;
PR = percentage reduction;
$CustoT$ = electricity/water total cost.

The external benefit was determined by quantifying, for the present analysis, the externalities associated with energy and water reduction. As mentioned, the externalities regarding to energy reduction used the ExternE results [15]. The primary energy parcels related to electricity production were from year 2000, the results are presented in the table 6.

Table 6: Parcel by kind of electrical energy [19] and externality cost.

Electricity Production	Fraction (%)	Externality Cost (€/kWh)
Coal	35	0.07
Hydro	26	0.0003
Oil	19	0.05
Natural Gas	16	0.02
Other Renewal	4	0.02

The external benefit was measured by the following expression:

$$B_E = PR \times ConsumoTE \sum (e_i \times f_i) \qquad (6)$$

were,
B_E = external benefit;
PR = percentage reduction;
$ConsumoTE$ = energy total consumption;
e_i = externality;
f_i = parcel by kind of electrical energy.

Concerning the solutions to minimise water consumption the hydro resources rate (TRH) was used to calculate the externalities associated [16]:

$$TRH = U = v \times trb_u \times c_{sec} \times c_{esc} \times c_{efic} \qquad (7)$$

were,
U = corresponded TRH for the use of water;
v = water volume (m^3);
trb_u = unitary hydro resources rate (€/m^3);
c_{sec} = sectorial coefficient (adimensional);
c_{esc} = scarce coefficient (adimensional);
c_{efic} = efficient coefficient (adimensional).

Applied to the present work the values are,

$$\begin{cases} \text{External Benefit } = TRH \\ trb_u = 0.015€/m^3 \\ c_{sec} = 1 \\ c_{esc} = 1.10 \\ c_{efic} = 0.85 \end{cases}$$

Usually for infrastructure projects the time period for their evaluation is between 20-30 years [12], which is an estimation of the economic life time expectancy. For the purposed of this study we admitted a time horizon of 20 years.

Regarding the discount rate the value adopted considered the average long term real nominal rate in Portugal that for the period between 1991 and 1998 was 5.1% and for the period between 1999 and 2003 was 1.7% [20]. Taking these values as reference we used as discount rates the values 2% and 5%.

Table 7 shows the results of social costs and benefits obtained for the evaluated solutions.

Economic viability is determined by the NPV value. If the value is positive project (adoption of solutions) is viable. To understand the number of years needed to recover the initial investment the payback was calculated. The values for these two parameters are presented in the Table 8.

In the aggregation process it was considered the implementation of the solutions altogether to evaluate the final performance of the Residence. After performing the analysis for each solution individually, the economic evaluation was made for the solutions aggregation. This analysis was executed in several steps so that no double counting occurs.

The first solutions to be aggregated were the ones that reduce the use of domestic water resulting in a reduction of 32% in fresh water consumption. Afterwards we introduced the solutions that accomplished energy efficiency, resulting in a reduction of 66% on energy consumption. Finally it was studied the production of electricity, for domestic use, through wind and photovoltaic power with capacity to meet in 100% the energy needed by the Residence. The results can be seen in Table 9.

Table 8: NPV and Payback values.

Sustainable Solutions	NPV [5%] (€)	NPV [2%] (€)	Pay Back [5%] (years)	Pay Back [2%] (years)
Double glazing	29 604	54 903	13	11
Outdoor Blinds	59 024	89 384	6	5
Efficient equipments	140 406	199 933	3	3
Efficient light bulbs	55 197	76 095	5	4
Solar collectors (100%)	143 587	215 020	5	5
Wind power energy	13 995	31 537	17	13
Photovoltaic energy (35%)	-291 102	-186 929	*	47
Flush reducers	18 409	25 894	2	2
Flow reducers	61 573	84 609	1	1

* Initial investment not recovered

4.3 Residence Classification by LiderA System

After the economic viability analysis of the aggregated solutions that could be implemented in the Residence, the LiderA system was used to estimate the performance levels acquired.

Regarding to the resource category (see Figure 3), relatively to the energy area the implementation of double glazing and outdoor blinds will contribute to a better performance in terms of passive energy (Criteria 10) of the Residence. On the other hand, together with efficient equipments, efficient light bulbs and solar collectors the reduction of electricity consumption (Criteria 11) is high (the classification changes from D to A+/A++). The introduction of renovation energy (wind and photovoltaic power) yields the production of clean energy from renovation sources (Criteria 12) for domestic usage. Regarding the water consumption the use of flow and flush reducers can reduce 32% of the total fresh water consumption (Criteria 16).

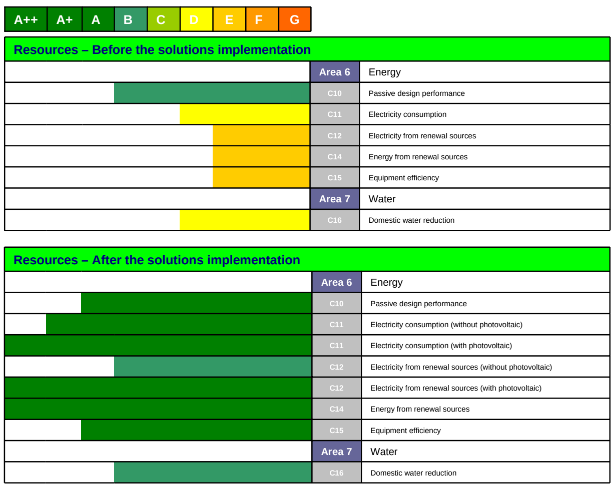

Figure 3: Result: Resources.

Considering the category of environmental loads (see Figure 4), at the level of effluents, by reducing the consumption of fresh water the waste water flow is also reduced. With the implementation of the solutions that reduce energy consumption and the solutions that produce clean energy results in the minimisation of CO_2 emissions.

It was also possible to obtain an estimation of the global Residence classification. The evaluation was made considering the reference situation and two alternative situations,

Table 7: Results of solution's costs and benefits.

Sustainable Solutions	Annuity Investment Cost [5%] (€/year)	Annuity Investment Cost [2%] (€/year)	Benefits: Private Bills Reduction (€/year)	Benefits: External Externalities Reduction (€/year)	Social Benefit (€/year)	B/C Ratio [5%]	B/C Ratio [2%]
Double glazing	3 410	2 525	4 343	1 443	5 786	1,7	2,3
Outdoor Blinds	2 207	1 634	5 211	1 732	6 943	3,1	4,3
Efficient equipments	2 347	1 737	10 218	3 396	13 614	5,8	7,8
Efficient light bulbs	1 412	1 045	4 087	1 358	5 445	3,9	5,2
Solar collectors (100%)	4 815	3 564	12 261	4 075	16 336	3,4	4,6
Wind power energy	2 889	2 138	3 011	1 001	4 012	1,4	1,9
Photovoltaic energy (35%)	47 183	34 928	17 881	5 943	23 824	0,5	0,7
Flush reducers	235	174	1 693	19	1 712	7,3	9,9
Flow reducers	327	242	5 210	58	5 268	16,1	21,7

Table 9: Economic viability assessment considering the solutions aggregated.

Aggregated Solutions	Investment Cost (€)	Annuity Investment Cost [5%] (€/year)	Annuity Investment Cost [2%] (€/year)	Benefits: Private Bills Reduction (€/year)	Benefits: External Externalities Reduction (€/year)
Aggregated solutions without photovoltaic energy	189 855	15 234	11 277	43 429	12 216
Aggregated solutions with photovoltaic energy (28,5%)	660 255	52 981	39 219	57 992	17 056

Aggregated Solutions	Social Benefit (€/year)	B/C Ratio [5%]	B/C Ratio [2%]	NPV [5%] (€)	NPV [2%] (€)	Pay Back [5%] (years)	Pay Back [2%] (years)
Aggregated solutions without photovoltaic energy	55 644	3,7	4,9	503 598	746 912	5	5
Aggregated solutions with photovoltaic energy (28,5%)	75 048	1,4	1,9	275 011	603 171	16	13

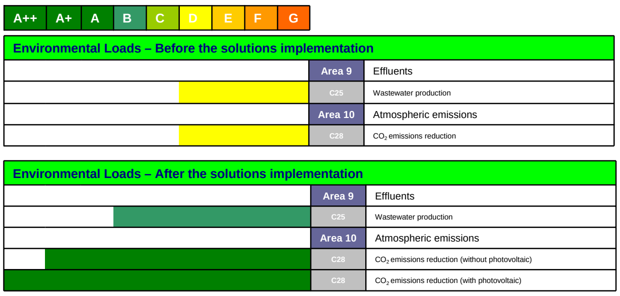

Figure 4: Result: Environmental Loads.

with and without the photovoltaic power solution. The score obtained is displayed on figure 5.

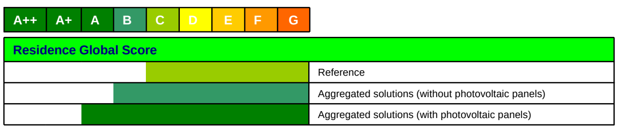

Figure 5: Global Residence Classification.

4.4 Interpretation and Discussion

The Table 10 demonstrates all the results of solutions taken individually and aggregated obtained by the cost-benefit analysis that was yield in this study.

It was verified for all the solutions under evaluation that the avoided externalities with the reduction in electricity and water consumption increase the social benefit.

According to ExternE the externalities associated with the production of electricity from fossil source are essentially derived from CO_2 emission. On this study, as can be seen in Table 6, 70% of the national electric energy production is from thermal electric centrals (coal, oil and natural gas). For this reason, the value of the externalities associated with the use of electric energy comes greatly from CO_2 emission.

Regarding to the solutions evaluation, the first four solutions (double glazing, outdoor blinds, efficient equipments and efficient light bulbs) are solutions that act directly in the electricity reduction. In the case of double glazing and outdoor blinds they also contribute to increase the thermal and acoustic comfort. From the questionnaires, 38% of the residents consider the bedroom cold in the winter and 42% consider the bedroom hot in the summer time. This reduction in the electricity consumption affects directly the electricity bill making it a private benefit.

The use of solar collectors meet 100% the hot water demands, situation that is equivalent to reduce 24% of the total energy used by the Residence. Therefore its implementation decreases the electricity bill and consequently creates a greater social benefit.

In the matter of implementing wind and photovoltaic power with the capacity to produce clean energy for domestic use,

Table 10: Cost-benefit analysis resume table.

Sustainable Solutions	Investment Cost (€)	Annuity Investment Cost [5%] (€/year)	Annuity Investment Cost [2%] (€/year)	Benefits		Social Benefit (€/year)	B/C Ratio [5%]	B/C Ratio [2%]	NPV [5%] (€)	NPV [2%] (€)	Pay Back [5%] (years)	Pay Back [2%] (years)
				Private Bills Reduction (€/year)	External Externalities Reduction (€/year)							
Double glazing	42 500	3 410	2 525	4 343	1 443	5 786	1,7	2,3	29 604	54 903	13	11
Outdoor Blinds	27 500	2 207	1 634	5 211	1 732	6 943	3,1	4,3	59 024	89 384	6	5
Efficient equipments	29 250	2 347	1 737	10 218	3 396	13 614	5,8	7,8	140 406	199 933	3	3
Efficient light bulbs	17 600	1 412	1 045	4 087	1 358	5 445	3,9	5,2	55 197	76 095	5	4
Solar collectors (100%)	60 000	4 815	3 564	12 261	4 075	16 336	3,4	4,6	143 587	215 020	5	5
Wind power energy	36 000	2 889	2 138	3 011	1 001	4 012	1,4	1,9	13 995	31 537	17	13
Photovoltaic energy (35%)	588 000	47 183	34 928	17 881	5 943	23 824	0,5	0,7	-291 102	-186 929	*	47
Flush reducers	2 925	235	174	1 693	19	1 712	7,3	9,9	18 409	25 894	2	2
Flow reducers	4 080	327	242	5 210	58	5 268	16,1	21,7	61 573	84 609	1	1
Aggregated solutions without photovoltaic energy	189 855	15 234	11 277	43 429	12 216	55 644	3,7	4,9	503 598	746 912	5	5
Aggregated solutions with photovoltaic energy (28,5%)	660 255	52 981	39 219	57 992	17 056	75 048	1,4	1,9	275 011	603 171	16	13

* Initial investment not recovered

its dimensioning considered the areas needed for implementation and the specifications for each solution. It was verified that with wind power alone it is possible to produce 5.9% of the energy required by the Residence and with the introduction of photovoltaic power this percentage arises to 35%.

Of all solutions, evaluated individually, only the photovoltaic power installation is not feasible because the costs exceeds the benefits.

Regarding the payback time of the solutions it can be seen that the photovoltaic power have a raised initial payback time. For this solution the payback time is sensitive to the discount rate used. This happens because when we increase the discount rate the present value is decreased. In this way, as the photovoltaic panels have a higher initial investment cost in comparison with the benefits that are provided, the recovery of the investment sustains over time and in result the payback time is larger for a bigger discount rate. This is the reason behind the impossibility to determinate the payback time for a discount factor of 5% meaning that the initial investment is never recovered and for a discount rate of 2% that period is 49 years (see Table 10).

Concerning to the other solutions, the double glazing and wind power presented respectively a payback time of 11 and 13 years for a discount rate of 2% and 13 and 17 years if the discount rate is 5%. All the others have a payback time of less than 10 years and the difference between different discount rates is small. This occurs because the initial investment is recovered through a small period of time. The flow and flush reducers' implementation have the smaller payback time (1 and 2 years respectively) and have also the greater benefit-cost ratio (B/C) meaning that the benefits that came from these solutions greatly exceeds their costs. From the NPV analysis it can be seen that the solutions that present the bigger value are the efficient equipments and the solar collectors. For these solutions the payback time is also very attractive (4 and 8 years respectively for a discount rate of 5%)

Taking in account the analysis extended to the solutions altogether, i.e., the evaluation of the solutions as a whole, with the exception of photovoltaic panels, we conclude that the payback time is 5 years regardless of the discount rate used. Considering now also the photovoltaic power, all the solutions aggregated have a major contribute in energy reduction, being possible to reduce 100% the electricity consumption from the public network and payback time states between 13 and 16 years at a discount rate of 2% and 5% respectively.

The cost-benefit analysis carried out allowed, for the time horizon adopted, calculating the costs and benefits of the given solutions and to determinate the economic viability of each one. The success of this analysis depends on the quantification of all the external costs associated. It is verified that the solutions identified, beyond the investment cost, also present benefits obtained from prevented externalities. The major difficulties on the calculation of the external costs are due to limited information existence and to the effort required by the methodologies for its quantification. In what concerns to the investment cost, the study undertaken revealed a lack of information that limited its determination. It was not possible to find the information of the installation costs, therefore it was only considered the acquisition cost.

5 Conclusion

The results indicate that in the process of building reconstruction/renovation, the reduction of energy and water consumption, ambient loads and the improvement of thermal and acoustic conditions constitute the main areas of intervention. From an economic point of view for the solutions taken individually, with the exception of photovoltaic energy, the net present value (NPV) is positive (which means they are viable) and the payback time ranges from 1 to 17 years (at a discount rate of 5%) and from 1 to 13 years (at a discount rate of 2%).

Considering the aggregated solutions the payback time is 16 years at a discount rate of 5% and 13 years at a discount rate of 2%. The environmental performance classification of the Residence according to LiderA, for the criteria where the solutions are applied, is between the level C and A++. This contribution leads to an overall change from level C (reference situation) to level A (aggregated solutions). Overall the implementation of the evaluated solutions leads to a reduction of 66% in the energy consumption and 32% in the water consumption, being possible to produce 100% of the electricity consumption of the Residence through wind and photovoltaic power.

With this work we conclude that there is a set of solutions which can be applied in the renovation of the Residence to improve the environmental performance of the building. In addition to the environmental benefits there are also economic benefits. The Cost-Benefit Analysis carried out proved to be a capable technique for evaluation the economic viability of the solutions that were identified. Beyond the costs it quantifies the benefits associated with the solutions' implementation. As a final conclusion, improving the environmental performance and using economic viable solutions the social benefit is increased.

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