ABSTRACT

The world population growth and the consequent increase in energy demand in recent years are making sustainability to become a key element in order to ensure the future of the society. In Spain, buildings account for 24% of total energy consumption, and within the buildings stock there is a group called "protected buildings" with low efficiency and therefore a large room for improvement, although constrained by different limitations and special requirements due to their condition. Through a study of the limitations of these buildings it’s possible to find the best solutions to make them more sustainable, focusing on reducing their energy consumption, on keeping the characteristic features of these buildings as part of the Spanish Historical Heritage, and on the economic terms of achieving all this.

Keywords: sustainability, energy efficiency, energy consumption, protected buildings in Spain, keeping the heritage.
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1. Introduction

The aim of this section is to set the scene, giving some background information, as well as explaining the main objective, and how the thesis has been conducted.

1.1. Background

Nowadays, talking about historic and protected buildings, could make come to mind the image of an impressive and majestic building, built hundreds of years ago, and still keeping today all its magnificence. When talking about “preservation”, it’s easy or usual to imagine minor repairs along the facades in order to disguise the effects of aging. Nothing is further from reality.

Firstly, a historic or protected building may seem like a fairly "normal" building, and what distinguishes it from others, are the techniques used during construction, or what it represents for the city or society because of its history. Similarly there are buildings of this type that can have an old and neglected aspect, which might make people think that is an uninhabited building. By saying this, what is pretended is to show that there are a large number of historic and protected buildings, whose type, size, shape, etc. varies greatly.

Secondly, "preservation" should be much more than make a few tweaks on the outside. Most of these buildings have a normal use, as would any other building, either as a home, an office, a cultural centre, etc., so that “to preserve” must allow the building not only to keep its aesthetics and its structural stability, but also achieving interior proper comfort conditions and avoiding excessive consumption.

Currently, the problem is that the preservation of these buildings is focused on the structural and aesthetic aspects, trying to keep building characteristics as much as possible, but not on the behaviour itself. Focusing on improving the performance of the building from an energy and comfort point of view, will bring along multiple benefits for the society in many different ways. Thus, the aim is to find a series of measures and implement solutions which allow to improve the sustainability of these listed buildings. This means improving their energy behaviour while maintaining and preserving their unique characteristics and keeping the historical heritage of the country.
Sustainable development is the path the society should follow in order to grow and progress, and the benefits to be gained from achieving the thesis goal are in line with the three pillars on which sustainable development is based.

![Sustainable development](image1.png)

Figure 1: sustainable development [1]

These three main pillars can be seen in figure 1, and are: economic factors, environmental factors, and social factors, and in the following lines, it could be observed the close relationship of each one with the main objective.

**Economic factors**

Since the number of protected historical buildings is much greater than it seems, reaching the objective would bring important economic benefits. By reducing the consumption of the building, the amount of money spent on buying that energy would also be reduced. While it is true that in some cases the cost of investment in measures to improve energy efficiency can be high, if the measures and systems chosen are adequate, the initial cost will be quickly surpassed by the savings from reduced consumption. It is also interesting to note that the maintenance of the heritage of the country in good might bring along other advantages, like the interest of different experts to study this heritage, or the interest of people from all over the world to visit it.
Environmental factors

The energy consumption is inevitably associated with the emissions of gases and pollutants (produced due to the generation of this energy) as well as a number of wastes that adversely affect the environment. The higher the energy consumption is, the higher the emission of these harmful elements will be (CO₂, other greenhouse gases, materials consumed after producing energy, etc.). Thus, reaching the goal, will allow to reduce the consumption, and therefore the emissions associated with it, producing less pollution and harmful wastes for the Environment. By doing this it’s important to note that the indoor quality must be kept (temperature, humidity, etc.), which means that reducing the consumption must not lead to having worse indoor conditions.

Social factors

Reducing the energy consumption is something that seems essential to ensure the future of our society, and in some cases it will be necessary to take many steps and make decisions that may harm other aspects of society. When "improving a building" some aspects like walls, shapes, heights, materials, etc. are altered, which in many cases will be a justified action, however when talking about historic and listed buildings, such alterations must be avoided as much as possible.

Since these buildings are part of the historical heritage of the country, which belongs to all its inhabitants, a proper maintenance, and preventing its alteration, will be without any doubt, a positive impact for the society.

It’s pointless aiming to fulfil all the requirements of one of these pillars, if the others are left behind. It’s important to work on all of them and try to develop them as much as possible.

1.2. Main objective

The aim is to increase the sustainability of protected buildings in Spain, taking into account the special requirements and constraints that Spanish law apply to them. It could be said therefore that the objectives are two, and both must be met simultaneously.
• On the one hand, the thesis tries to show the importance of increasing the energy efficiency of this group of buildings and reducing their energy consumption, while trying to find out which action or actions will get better results in order to reach the objective.
• On the other hand, the objective is also to maintain the Historical Heritage of the country as unchanged as possible, and particularly the listed buildings and their most characteristic features.

This way, and since both goals must be met simultaneously, this Thesis try to find the best actions to implement, which allow the building to have a better performance without altering the unique elements the building has. To achieve this, it’s essential to know the type and level of protection for each building according to the law, in order to know what elements can be modified and which not, or at least how severe the competent body will be regarding the changes. From this moment, only actions “allowed” by the Law, will be implemented to improve the energy performance of the building.

These "best measures to implement" will be evaluated not only under an energy point of view, but also considering the economic aspect, which is always important, but even more now, due to the current economic recession.

Besides, there will be a discussion related to the Thesis conducted by Carmen Coronada Martínez Pérez, whom has been working on a similar topic, but based on the Swedish Law instead of on the Spanish one.

If the goal is reached, and the work comes to fruition, this Thesis could be used as a “guide” for all those seeking to "increase the sustainability" of protected buildings in Spain.

1.3. Method

When talking about the method or approach, it could be said it starts from a general analysis of the current situation regarding energy demand, protection of the Heritage in Spain, energy efficiency, etc. to study a particular building of northern Spain, and simulating different scenarios based on energy performance. This way, it has been possible to perform several discussions on "keeping the Heritage", "expenses incurred" and “reduction in energy consumption or increase in energy efficiency”.

The steps followed are as follows.
• **Literature review**: as a first step, it’s been necessary to read and analyse texts regarding building protection in Spain. Thus it was possible to obtain information on how to protect buildings, types of protections, and levels, etc. according to which, more or less alterations or changes on the building are allowed. As other sources, it’s important to highlight the importance of "The Spanish Constitution," "The Technical Building Code", university related paper works, "The Spanish Ministry of Culture" etc.

• **Contact with the famous architect Mr. José María Pérez, Peridis**: Mr José María is a famous and important architect in Spain. He is one of the directors of the architecture studio “Gaforidis [2]”, which is specialized in architectural heritage rehabilitation and recovery. Due to this, he has a broad knowledge on issues related to this thesis, and his help and support have been invaluable.

• **Simulation**: once explained everything needed about energy and protection in buildings, and after obtaining enough information about the building “El Espolón”, the technical part of the work is based on a simulation of this protected building, by using the energy software Design Builder [3]. As a result it’s been possible to run different scenarios characterized by different measures and actions, and this way, a set of conclusions can be drawn for each one of them. Likewise, these simulations have made possible to decide which are the advantages and disadvantages of each option.

• **Discussions and conclusions**: thanks to all the information gathered and the results obtained by running the Design Builder software, it has been possible to discuss about different matters regarding the best measures to be implemented, and all that is important and should be taken into account. Similarly, this part of the Thesis will be based on a thorough discussion of three key aspect such as: “decreasing energy demand”, “keeping the heritage of the country” and “expenses incurred by it all”. It must also be mentioned the comparison carried out between the Spanish and Swedish system regarding protection of buildings, and how to proceed to make changes in order to “modify” their performance.

1.4. **Problems faced**

Although throughout the completion of this project different problems and impediments have emerged, the highlights or those which have really complicated the normal development of the thesis have been the followings.
• **Measures to implement**: when making decisions about what actions could or could not be implemented to improve the behaviour of the building, considering its level of protection, there have been complications because the intervention criteria sometimes leave large gaps in terms of what you may not alter, although sometimes the problem is the other way round, since the different criteria overlap and it is not easy to decide which will be the most appropriate. Also it should be noted that these criteria are not specific regarding what items can or cannot be altered, but give broad indications of the need “to prevent alteration of the building”. Thus, in many cases, the only way is following the own intuition on what action to take, and hope that, in the eyes of the competent body the savings achieved by them exceed the disadvantages of having altered some building elements. This problem was solved in most of the occasions with the help of architect Peridis, and his experience in similar projects in the past.

• **Costs**: in relation to the measures to implemented, an economic study has been conducted. It was relatively easy to find information regarding the prices of new elements (such as LED’s, new windows, etc..), however, is not that easy to estimate or try to find the cost of installation or implementation of these new measures, taking into account factors such as time, personnel, supplementary materials, etc.

• **Design Builder**: the main problem when simulating using this software is that certain measures which were supposed to be implemented in order to improve the efficiency of the building, were not available in Design Builder, such as adding interior windows, or including aerators to reduce water consumption. The way to fix this, has been carrying out a series of calculations on the behaviour of these measures that could not be implemented (heat transfer coefficients, consumption, etc.), and then create a new item in Design Builder with the values obtained thanks to the calculations (in the case of windows, for example, the thermal behaviour that would have an inner and an outer window working together was calculated, and then, this value was associated with a “normal” window created with the software).
2. Current situation

This section explains the current situation of different aspects which are important for the development of the thesis, like energy demand, building protection in Spain, problems to solve and actions to carry out, etc.

2.1. Energy demand

Before digging deeper in the energy demand amazing growth, it’s necessary to highlight the reasons that are causing this trend. The unstoppable world population growth is a recurrent fact that started many years ago, however, it’s been during the last years when this trend has become a key aspect for the society due to the spectacular numbers.

Figure 2: World total population and population growth rate. [4]

The percentages in blue show the population growth rate of every year. As it can be observed in figure 2, the world population had about 2500 million people in 1950, reaching the amazing number of 6000 million people in year 2000. This way, the population increased by 3500 million people in just 50 years. However, the most impressive growth has occurred over the last decade. In just 10 years, the world population counted with 1000 million more people, making a total of 7000 million people, a big population that is currently growing, and it will continue to grow for the rest of the
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century as can be seen in the figure. Similarly, development and living standards also increase and improve all over the world, which leads to an important change in trends, lifestyle and demands of each single person.

Population is shifting from the countryside to big cities, the different jobs are more automatized, dwellings are higher developed, individual requirements are higher, etc. This all leads to a general consumption growth, from crops, food and wood, to soil, water and energy resources.

This research project will be focused on making a positive impact on these energy resources. More concretely, it will be focused on improving energy efficiency in a special type of buildings, considering a better energy use, and lowering energy resources consumption. It has to be said, that lowering the consumption of other type of resources can also be achieved, as a secondary target.

**Global energy demand growth**

As it can be observed in figure 3, the global energy demand is growing enormously and it will continue to grow according to the forecasts. As said in this section, this growth is mainly caused by the growth of population and GPD. Considering that these two factors are difficult to control or to limit, using energy in an efficient way is something that comes to mind. Improving energy efficiency will allow us to reduce the consumption even if the population and the GPD continue to grow (something that is expected).

At this point, buildings become a key player since they account for 40% of world annual energy consumption. Due to this, it’s important to achieve significant improvements in buildings energy efficiency, to reduce the global energy demand.

*Figure 3: Global energy demand growth. [5]*
2.2. Importance of the buildings regarding resources consumption

Nowadays, the data shows that buildings are very important global resources consumers. Saying “very important” is not an exaggeration, considering that buildings are the world largest energy consumers (they account for 40% of all energy demand) [6]. Despite this number is not as alarming in Spain as in the rest of the world, since the weather and climatic conditions are softer than in an average country, buildings account for a 24% of total country energy demand [7]. Taking a general building as an example, almost half of total consumption (46%) is caused by heating, while cooling accounts for a small percentage of the total [8]. Due to this, in Spain, a country with many warm areas and without extreme cold zones, buildings energy consumption is smaller than the world average, being approximately one fourth of country energy demand.

Buildings are not only the cause of high amounts of energy consumption, but also the cause of many contaminants and elements that damage the environment and the life of human beings and different species. It has to be said that some of these contaminant are directly linked with the energy consumption. Currently, about a 33% of contaminants causing the greenhouse effect in Spain are produced by buildings [9]. This percentage has grown by 42% over the last 20 years.

Taking into account this information, buildings play a key role and are a key element in order to meet the goal of improving efficiency and sustainability and assuring a future for our planet.

At this point, and thanks to all the previous data, it can be observed that buildings impact enormously on the planet, however, buildings are totally necessary for human beings, which need proper indoor conditions in the building to develop their activities. Therefore in order the improve the current situation it’s necessary to act, implementing a bunch of measures and strategies that allow us to improve energy efficiency in buildings in many different ways, and not only reducing energy consumption, but also reducing the emissions of pollutants linked to this consumption.

Before digging deeper into the importance of buildings regarding these matters, and all that can be achieved by improving them, it’s necessary and useful to explain what exactly “energy efficiency” is. This way it would be much easier to understand one of the goals of this project, and those things that must be done in order to reduce the energy consumption.
2.3. Energy efficiency

Energy efficiency is to deliver more services for the same energy input. This also leads to deliver the same services for less energy inputs. It’s a way of managing and restraining the growth in energy consumption [6]. It should be highlighted that the service must not be affected in a negative. Energy efficiency has many different advantages and amongst them we could highlight the following:

- **Ensuring the future**: the consumption of energy will be smaller and thus, the pollutants and emissions associated with it.

- **Environment**: day by day the society is more concerned about the environmental issues and due to this the law and the requirements are getting stricter. Improving energy efficiency leads to increasing the possibilities of meeting those requirements.

- **Operation costs decrease**: since energy consumption decrease results in lowering the costs.

Similarly, it’s important to pay special attention to the 4 main areas on which energy efficiency is based. Besides, since these 4 areas are the drivers of the building energy efficiency, all the important measures or action to implement, must be aligned with them. These main areas are: [10]

- **Building envelope**: all those elements limiting the interior comfort zone and the area outside the building.

- **Energy systems**: all those systems in charge of reaching the right internal comfort conditions such as chillers, boilers, heaters, lighting, etc. It’s vital using the right type of element in each concrete case and trying to get the highest performance.

- **Intelligent use of the systems**: due to the fact that even if our system is the most efficient one, there is nothing to do or improve if this system is working much longer than necessary. This way it’s important to implement a number of sensors or measuring systems which allow us to use the system the right amount of time and with the right amount of energy intensity.

- **User education**: teaching the user how to use and not to use the building, in order not to waste the resources.
2.4. Types of buildings

As it is known, there are many types of buildings considering size, shape, use, location, orientation, method used during construction, etc. However, in order to decide on which buildings this project will be focused throughout its development, the main differentiation will be based on how old the buildings are, and within this distinction, it will be based on whether or not these buildings are considered historic or protected, and thus, if special requirements and restrictions apply to them.

Nowadays, there is a bunch of actions or measures being carried out in order to improve the new buildings, or those that are under construction. In this case “Improving” means decreasing energy consumption, getting a better insulation, etc. which leads to a better energy efficiency in these buildings. There is no doubt that these measures will bring along very positive results for the future, when talking about energy, and that this fact is totally aligned with the objective of improving energy efficiency, however, it’s necessary to consider and keep in mind the following.

![Buildings stock in Spain](image)

**Figure 4: Breakdown of buildings in Spain according to their age or year of construction [11].**

Considering the data of Figure 4, it can be inferred that even if we consider all the buildings built after the year 1970 as “new” (something that would be really optimistic since we should name new building as the ones built over the last 10 years and not 40 years), and we invest in them trying to improve their energy efficiency, the possibilities to go further and achieve our goal would be limited, since almost 40% of the buildings of the country are not included in this group. Likewise, the older the building, the worse the
energy performance, either caused by a poor insulation, by a low performance of the systems, etc. which results that aside from accounting for a 40% of the total, the energy performance of these buildings is worse, and consequently, an improvement of their efficiency is doubly necessary.

In conclusion, to achieve an improvement in the energy efficiency of the buildings in Spain, it’s necessary not only to implement measures for the new and under construction buildings, but also to renovate deeply the old buildings, which have the worst performance.

This project will be focused on a group of buildings within the group built before 1970. A set formed by those buildings which due to their age, identity, value or history, are considered protected or historic, and thus, are limited by special regulations, requirements, and protections.

2.5. Importance of keeping the heritage

After reviewing the data shown in section 2, it’s evident the importance of improving energy efficiency and decreasing energy consumption. However, before analyzing deeper the historic and protected buildings, it’s necessary to understand the importance of keeping a country’s heritage.

The contents of this paragraph have been taken from “The Spanish Ministry of Culture [12]” and from the “Spanish Historic Heritage law [13]”. The Spanish historic heritage is formed by immovable and movable properties, which have artistic, historic, archeological, scientific or technical value. Likewise, documentary elements, natural sites, gardens and parks with historic, artistic or anthropologic value are also part of this heritage. Considering the scope and amplitude of this concept, and the large number of elements it covers, the Spanish law establishes the main levels of protection

- **Bien de Interés Cultural (BIC)**: it’s a definition valid to design and protect immovable and movable properties. It represents the highest recognition regarding heritage concerns. This leads to strong control by the Government and important maintenance measures. This type of properties are included and listed in a register called “Registro General del BIC”.

- **Inventario**: definition valid for movable properties, which want to be recognized as Historic Heritage, and also want the Government to keep a constant track of their elements.
• **Patrimonios especiales**: this definition includes the elements known as archeological, documentary, and bibliographic documents.

Amongst these levels there is one that would be really important for the development of this project. What will be important for it, will be the *immovable properties* within the **“Bienes de Interes Cultural” protection**. This way, BIC classify their elements into different groups: Monuments, Historic Gardens, Historic Areas, Historic Sites and Archaeological Zones. Although each of these elements have their own restrictions and limitations, two big groups within the BIC can be set.

- **Figuras zonales (area related protection)**: usually the elements within this group cover large areas and affect more than one landlord. The protection of these elements is determined by the “Urban planning office”. Within this group we can find: Historic areas, Historic sites and Archaeological zones.
- **Figuras no zonales (non area related protection)**: they affect only one immovable each, and every single activity carried out over them requires authorization from the “Central Cultural Administration”. Within this group we can find elements like Historic monument and Historic garden.

Previously, just one level out of the three Spanish levels of protection was important for the development of this project, and the same happens at this point. The interest will be focused on “Historic monuments”, denomination under which we could find “Historic buildings”. It has to be remember, that this project will try to improve the energy efficiency of a building itself (non area related element), and not of a zone or group of buildings (area related element).

“**Historic Monuments**” can be defined as those immovable goods which represent architectural or engineering constructions, with a high historic, cultural, scientific or social interest for the society. The Spanish Historic Heritage Law 16/1985 controls the activity of this type of goods and sets their level of protection.

### 2.6. Process by which a building becomes protected

The information of this section has been mainly taken from “The Spanish Ministry of Culture [12]”. The competent bodies taking part in the process by which a building become protected are

**Competent bodies**

- Government of Spain
- Historic Heritage Protection Board
Competent body within each area or province

Mandatory process to get the building protected

I. Make a proposal: everybody can make a proposal in order to protect a building. Either a common person or the owner of a building that considers it should be protected, as well as the Central Government or other competent bodies which consider a building has a special importance for the heritage of the country.

II. Analysis and study of the proposal: the competent bodies will carry out an analyse and deep study of the proposal in order to know if the building deserves the protection, and, in an affirmative case, determine also what level of protection is the most adequate. Usually the proposal for a building is reviewed and checked out by the competent body of its area, however, sometimes it’s the Central Government (through the Ministry of Culture) the ones that reviews the proposal and makes a decision. This use to occur when the building is better known and may have a bigger importance for the heritage of the country.

III. Processing and updating the information: after the decision is made, the Historic Heritage Protection Board carries out the necessary paperwork to indicate any new building protection. This way, it collects and updates information from the various relevant agencies or competent bodies regarding protection of buildings, so that anyone can quickly learn which buildings are protected and at what level.

2.7. Intervention criteria, levels of protection, types of intervention regarding objective.

When carrying out an intervention in an historic building, many different criteria must be taken into account. The problem is when sometimes these criteria overlap, contradict, or leave gaps, when a decision about how to intervene has to be taken. This is mainly caused by the existence of both a criteria for all the BIC in general, and a different set of criteria for historic buildings in particular. Thus, sometimes it’s difficult to figure out if a specific action or measure should be carried out, or if on the other hand, it could be banned by the body in charge. This could be seen along the following set of criteria [14].
Intervention criteria for BIC

An historic building is part of the BIC group, and due to this, it must meet the general criteria of the group.

- **Minimum intervention**: actions like restoration, conservation, empowerment, etc. can be carried out, as soon as every single action that may damage or endanger the building is avoided or decreased.
- **Differentiation**: in case it is needed to add elements to different parts of the building due to lack or poor quality of the current ones, it will be done in a harmonious way, but distinguishing the new element for the old ones in order to avoid historical and art forgery.
- **Documentation**: all the actions carried out will be gathered in a written report, describing the process and including pictures and images.

Intervention criteria for Monuments/Historic buildings

The following criteria must also be met when carrying out different actions or works in historic buildings. It’s just necessary to fill in a form with the changes that want to be carried out, and explaining what will be achieve thanks to that changes. Considering that an historic building is also a BIC, thus, any changes that want to be implement in these buildings must meet both set of criteria. As could be seen along this section, sometimes this is just not possible.

- **All the historic values and main characteristics of the building must be kept**. Even considering this, the use of different techniques, elements and modern materials might be permitted if this allows the building to adapt better to its use. Those characteristics related to the external shape of the building must be kept, although some exceptions may apply in some cases and if the office in charge permit it. (A good example would be making energy consumption drop by 80%, then many actions would be permitted. This will always depend on the decision of the body in charge though). All this means that the criterion is not really concrete, since all the actions and changes will be judged in a subjective way, according to what the competent body thinks or considers. This way, if a reduction of 50% is considered enough then the actions will be allowed, however, it might be that this reduction is not consider big enough so the building could not be change in that way.
- **It will be permitted to carry out partial or complete reconstructions of the building**, but only in cases in which enough original elements for this action are
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available. Likewise, false additions are prohibited, since that could endanger the historical authenticity of the property.

In order to show another example, we could talk about the differentiation criterion within the BIC set, and about the second criterion within the monuments/historic buildings set of criteria. In the first one, the use of different materials is allowed as long as it’s easy for a viewer to determine that those materials are not original. However, in the second one, only original materials can be used when trying to make changes to the building.

After talking about the two groups of requirements a historic building should fulfil, due to the fact it’s both a BIC and a Historic monument (something that sometimes is impossible since there are some conflicts), there are still more levels to split these buildings into, regarding their importance or repercussion. The following set of differentiations and requirements will allow us to frame more accurately each building on its corresponding "group". This way it will be much easier to know what type of interventions can or cannot be carried out. In conclusion, the better and deeper the building is classified, the easier is to figure out what action can be taken to improve it or adapt it.

2.8. Levels of protection

In order to protect the historic built heritage, a set of rules called “Catálogos de edificios protegidos” were established, with three main levels of protection. The protected buildings will be classified into these three levels[15].

1. Buildings under level 1 of protection: these are totally protected buildings. This way, all the characteristics of the building must be kept, characteristics regarding construction, architecture, volume, size, shape, decoration, etc. The buildings under this level of protection are split into two different groups or sublevels.
   a. Singular: this denomination includes those buildings which are relevant or highly important for the Spanish architecture or state-of-the-art. They also represent a milestone in the city structure.
   b. Integral: this group includes high quality buildings with large architectural and environmental values.

2. Buildings with level 2 of protection: this group includes as well buildings highly valued regarding volumes, construction, shape, decoration, etc. and with a great interest for the society. However, they have in their interior elements worse valued or less important, and thus, more changes and interventions are allowed for this group. This level also has two sublevels as the previous one.
a. **Structural**: within this group, the buildings have enough number of values to merit protection, values due to both, its volume and its major architectural elements.

b. **Volumetric**: the greatest value of these buildings are the successful integration with the landscape and the urban area, although they may also have certain architectural features that are worth to preserve.

3. **Buildings with level of protection 3**: within this level, the protection does not cover the entire building, only certain values. Like the ones above, this level is divided into two sublevels of protection.

   a. **Partial**: only those elements with greater value, characterizing the building and making easier to understand its era, style and function, are protected.

   b. **Environmental**: within this sublevel, what is protected are the elements and values of the façade due to their integration into the city landscape. The facade is considered as an element that contributes to the understanding of the urban landscape, but that does not necessarily require physical maintenance.

**CLASSIFICATION FOR PROTECTED ELEMENTS IN SPAIN**

![Figure 5. Classification of protected elements in Spain](image)

Thanks to figure 5, it’s possible to see in an easier way how protected elements are classified in Spain.
2.9. Types of intervention regarding the main objective.

As buildings have been listed based on their levels of protection, it’s also important to differentiate between types of intervention, depending on its purpose, and depending on what they try to achieve in the building. Based on this purpose, the limitations will be more or less relaxed, and bodies will be more or less permissive when judging what actions may or may not be carried out. An example to understand this more easily is the following[16].

A work of consolidation is carried out to ensure proper structural stability of the building, which means that the building will not collapse. In order to achieve this, even when the building has to be modified in a considerable way, the competent body will give its approval, since they could be risking the stability of the whole building just to avoid some changes in it.

On the other hand, in a rehabilitation work, the main objective (among many other) is to give the building a new functionality. In this case, the board will not be as benevolent as in the previous case, and it will be harder to get an affirmative answer or permission coming from them. Everything will depend on the board itself and on the advantages that goes along with the new functionality proposed.

1. Restoration work: such works are carried out in order to preserve the aesthetics of a building, while maintaining its functionality and preserving the historical value of it. When carrying out these works in the façade, it’s mandatory to use materials that match the original building. In case it’s necessary to change structural elements, it will be mandatory to use the same techniques and materials as in the original building. Likewise, when working on external parts of the buildings, it’s necessary to use the original colours and techniques.

2. Conservation works: are those works that are performed to repair any damage that has occurred in the building due to the passage of time or the natural use. The building must seem unchanged, so it’s mandatory the use of materials similar to the originals, or at least, with same features, colour, shape, etc.

3. Consolidation works: these works are aimed to reinforce or replace damaged elements in order to ensure proper stability of the building. It’s vital to use structural materials whose functions are similar to that of the original, so that the operation of the building remain the same. If this cannot be done, the materials used must ensure, at least, proper operation and a correct structural system.
4. **Rehabilitation Works**: those carried out to repair a building, so that respects the historic value of this, his aesthetic is preserved, and a new functionality is given. This new feature should be compatible with the conditions and prerequisites of the building. The main outcome or objective to be achieved, is one of the following two:

   a. **Functional adaptation**: since the aim is to give the building better conditions regarding the requirements of the CTE (Código Técnico de la Edificación or Technical Building Code), inside which it can be found the section “Energy Saving”.

   b. **Structural fit**: since the aim is to make the building have the proper characteristics regarding structural resistance, stability, etc.

First of all, it’s necessary to carry out a previous study of the building in order to determine its current condition. After this, within rehabilitation works, three different types may be stated.

   a. **Refurbishment works**: all internal elements of the building will be preserved, and external appearance will not be altered.

   b. **Restructuration works**: façades, roofs and their materials may not be modified.

   c. **Works affecting the exterior of the building**: they must be coherent with the materials used in the building and their shape.

5. **Reconfiguration works**: original materials should be used, and it’s forbidden to introduce different constructive techniques from those of the surrounding buildings.

6. **Reconstruction works**: which are a type of interventions that try to restore original features that are gone, trying to faithfully reproduce how these features were originally.

Those interventions aligned with the thesis objective of “increasing energy efficiency” are the “rehabilitation works focused on functional adaptation of the building. These interventions allow to take a series of measures in order to give the building a new functionality. As an example of this new functionality, it could be stated a decrease in energy consumption, increasing the efficiency of power generation systems, a reduction in the losses of the envelope, etc.

Once the building is correctly classified, and knowing well what kind of actions could be carried out according to the rules and the requirements, and knowing also the most
suitable type of intervention to achieve our goal, it seems that it’s time to figure out what measures are the most appropriate to increase the efficiency of the building. However, before reaching this point, it is worth analysing what are the main problems these buildings use to have. This way it could be possible not only to improve elements in order to increase energy efficiency, but also to delete or to reduce those elements preventing the building to reach a high performance.

2.10. Main problems these type of buildings use to face

Previously, there has been a section based on the pillars or drivers of energy efficiency. The main problems protected buildings usually have are aligned with these pillars, so that we could classify them in a simple and easy way to understand, by breaking them down into four groups.

<table>
<thead>
<tr>
<th>Energy efficiency drivers</th>
<th>Main problems these buildings use to face</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope</td>
<td>• Inexistent or inadequate insulation</td>
</tr>
<tr>
<td></td>
<td>• Infiltration or excessive air leakage</td>
</tr>
<tr>
<td>Energy systems</td>
<td>• Inadequate energy systems or with poor performance</td>
</tr>
<tr>
<td>Intelligent use of the systems</td>
<td>• Incorrect adjustment of the systems (temperature and power)</td>
</tr>
<tr>
<td>Users education</td>
<td>• Using of the systems when needed</td>
</tr>
</tbody>
</table>

Table 1. Most common problems protected buildings use to have.

According to architect Peridis, these are generally the main problems affecting protected buildings. Many of them are generalized for any type of building, such as improper adjustment of the systems, although others such as excessive air infiltration, are more typical of listed buildings due to their age, materials, or bad condition.

A series of measures expected to eliminate or reduce these problems, will be presented below, hoping they will help to achieve the objective of increasing energy efficiency in protected buildings, making them more sustainable.
2.11. Possible measures or action to take in order to improve energy efficiency

Similarly as it happened when talking about the main problems protected buildings use to have, the main actions. Within each of these drivers or in connection with them, there will be a series of steps or elements to take into account. Elements to focus on so as the goal can be reached.

Building envelope (passive actions)

A. Building envelope is defined as those building elements that separate or delimit habitable interior spaces of the building, and those which are not, and the external environment.

Although the main goal that want to achieved by improving the building envelope is to improve the thermal insulation, there are many other reasons why passive improvements are a good choice, such as

- Acoustic insulation
- Avoiding condensation
- Keeping the room cool in summer and warm in winter
- Adapting the building to legislation

Getting back to the main goal, a key characteristic for this thesis regarding building envelope, will be the U-value or “heat transfer coefficient”, which is directly related to the loss or gain of heat of a building, and it’s a value that will try to be minimized in order to improve the thermal performance of the building. Since one of the major problems of these buildings is the lack of insulation or its poor quality, by adding proper insulation or by improving the existent one, the thermal losses will be significantly reduced.

The elements of the building envelope to which the thesis will pay special attention are:

- Walls: as it happens with any element of the building envelope, the main objective is to get a reduced U-value or “heat transfer coefficient”. As can be observed below thanks to the formula, the “heat transfer coefficient” is directly related to (k) thermal conductivity, and inversely related to the thickness of the wall (L).

\[
U = \frac{1}{R_{tot}} = \frac{k}{L}
\]
Thus, the objective is to get a wall comprising one or more layers of material of low thermal conductivity, and as thick as possible, but without altering the aesthetics of the building and its habitability. Since our particular building is protected, the changes in the outer facade must be minimal or as small as possible, so that a possible solution is either to introduce intermediate materials or creating new inner layers.

- **Roofs**: roof surfaces are those parts of the buildings that suffer the most the adverse weather conditions. In fact, these parts usually account for a 30% of the envelope heat losses [17], so it’s important to pay special attention to them. Besides, apart from all those limitations applying to walls, when talking about roof surfaces some other limitations make their appearance.
  - On the one hand, while the requirements regarding wall thickness are relatively free, when talking about roofs this characteristic is much more limited for structural reasons, since apart from improving the thermal performance of the building, it must continue fulfilling the structural and security requirements.
  - On the other hand, one of the main missions of the roof if not the most important one, is to prevent the entry of rain water into the building. Thus, the use of waterproof layers is required, which will involve some kind of restriction when choosing which layers are the best option from an thermal stand point, to use and how thick should each have well established in a way that thickness exceeds a limit, so that the roof can meet all the requirements demanded

- **Openings**: although their contribution to the envelope in percentage is much lower than the one of the previous elements, an appropriate glazing is key to achieve a good thermal performance of the building envelope, since windows have much higher heat losses or gains in general. The two key factors to consider for glazing are:
  - Percentage of glazing compared to wall: as recently stated, the thermal performance is worse than that of walls and roofs, so the higher the value of this percentage, the greater the heat losses of the building.
  - Materials used: as it happens with walls and roofs, a key factor to consider is the “heat transfer coefficient”. The choice of materials with low thermal conductivities and enough thickness, or the overlapping of several of these materials will lead to smaller heat losses or gains.

It’s to be noted that the use of suitable materials for glazing will reduce heat losses and thus, it will not be necessary to modify the percentage of glazing, something that sometimes will be impossible to carry out since the building is
already built or due to structural matters. Apart from this, by reducing that percentage, the lighting consumption would increase, since the natural light would have less room to access the building from the outside.

As it occurs with the walls, the changes on the outer part of the windows could alter the aesthetic features of the building. Thus, a possible solution to improve the thermal performance of the openings, will be to add internal windows to the existing ones. By doing this, it’s possible to get a better thermal behaviour while the values and features of the building are not altered, which means that energy efficiency is increased and the heritage keeps protected.

B. **Infiltration, ventilation, air leakage**: it has to be considered, that there are many other elements affecting the performance of the envelope. To be more concrete, approximately a 30% of total heat losses or gains are caused by external ventilation, infiltration, and air leakage. This number may vary, and it could be much higher, as could be observed when analysing the building “El Espolón”.

Ventilation or air renovation is something mandatory in buildings, and necessary to obtain adequate comfort conditions, however, it’s important to avoid or try to reduce those undesired infiltrations or air leakages, since they affect enormously the performance of the building. That is why improving the envelope does not only imply using materials with the best characteristics, but also repairing the existing cracks and sealing joints to reduce the infiltration. Similarly, the ventilation must be carried out when needed, so it’s possible to keep a balance between air renovation and heat losses.

Energy systems (active actions)

So far it has been highlighted the importance of having a proper insulation so that it’s easier to maintain the internal comfort conditions, yet none of this helps, if these internal comfort conditions are not produced in an efficient manner and avoiding energy waste.

These type of actions have a special interest when talking about listed buildings, and will provide great flexibility to all that is intended to accomplish. Most of the measures related with HVAC’s, lighting, domestic hot water, etc. don’t pose a major impact on the appearance of the building. The identity, structure, or most characteristic elements of the
Achieving sustainability in protected buildings in Spain

building will not be substantially affected, which will lead to a large number of possibilities when talking about active measures to implement.

A. HVAC’s: the building needs to have right indoor comfort conditions. This conditions imply needs for heating, cooling, and ventilation. The HVAC let’s meet these requirements, however, is absolutely essential that the type of system chosen is the appropriate. Talking the right type of system includes: mode of operation, sizing, performance, etc. By using the right system for each building, it will be easier to achieve higher levels of efficiency. The drawback of implementing this measure or changing the current system is the high price and the high investment needed.

B. Lighting: in the same way that appropriate indoor conditions are needed, it is also essential to have proper lighting of the spaces. Not all environments require the same type or power of lighting, since there are many factors to consider such as: activity, amount of natural light, number of people, etc. It’s important to keep in mind that the lighting also produces heat, something to consider when choosing the other energy systems. Thus, taking into account that lighting affects the energy consumption of the building in two aspects, its importance and room for improvement are really big, especially when knowing that the costs of the lighting systems are quite reasonable.

C. Domestic hot water (DHW): despite the consumption associated to it is not really big, it is another aspect to consider when trying to get a higher efficiency in our building, mainly because changes related to DHW will barely affect the characteristic elements of a building as a protected entity.

Intelligent use of the systems

While it is true that when comparing this "intelligent use of the systems", with the envelope and energy systems, it may look like a minor point, however nothing is further from reality. A good envelope insulation, a low consumption, and a high performance of the systems are worth incredibly less if the indoor temperature set is not the adequate or
A. **Temperature sensors and thermostats**: it has to be taken into consideration that it is essential to set logical temperatures for the interior of the building. For example it makes no sense and it’s inefficient to fix an interior temperature of 20 ºC during summer and 25 ºC during the winter. Apart from this, it’s also necessary to ensure that these temperatures will be kept somehow. The temperature sensors or thermostats, are very simple devices that can make the building get large energy savings. By using these devices all over the building, it’s easy to adjust the temperature to the desired value, avoiding this way energy wastes.

B. **Light sensors**: with this type of sensors just the right amount of artificial light would be used. A greater amount of natural light coming from the outside, the lower the intensity provided by the artificial lights. In a protected property, and more specifically in our building of Santander, in which the windows have a considerable size, these sensors could be a good method to save energy.

C. **Movement sensors**: apart from setting the light intensity thanks to the light sensors, it is possible to install motion sensors, so that lights remain always switched off, and are lit when the sensor detects there is someone in that particular space. These sensors along with light sensors would optimize the artificial lighting usage within the building.

**User education**

Apart from all the technical and technological advances that will help us to increase energy efficiency, we cannot forget that the human beings will be the ones using the buildings. Because of this, all previous improvements would be useless if the user of the building just wastes the energy.

Unfortunately, user education regarding energy use is impossible or really difficult to measure, and this is why it’s important to make an effort to improve the performances of the user even while at first glance it may seem that there are no positive results. Since this aspect is more qualitative than quantitative, it is not taken into account when running
simulations and developing different scenarios, however, user education is a key aspect to consider if we really want to improve considerably the energy efficiency of buildings.

3. El Espolón de Comillas, Santander, Spain

This section contains all the information related to the building “El Espolón”, shown above in figure 6, on which the simulation will be based.
3.1. Brief description of the building

The building "El Espolón" is a famous old building in the town of Comillas, in northern Spain. After structural rehabilitation is intended to be a cultural centre so that everybody can enjoy it throughout the area, and it will have amongst other services, a library, meeting rooms, workshops room to develop various activities, changing rooms, toilets etc.

3.2. Location

The building is located in the town of Comillas, within the Santander province, in northern Spain. The following map shows the exact location.

Figures 7 Location of the city [19]. Figure 8. Panoramic view of the city of Comillas [20].

Below there is a table with the town longitude and latitude, and information about the average temperatures in the area. These temperatures will make easier to understand the data obtained from the simulations.
As it can be inferred from table 2, the town has soft average temperatures during the winter, and during the summer, an average temperature of approximately 19ºC, lower than what is usual throughout Spain.

### 3.3. Brief history of the building

The building “El Espolón” of the Ram was commissioned in 1794 by Juan Domingo González Reguera, Archbishop of Lima. In 1802, “The Royal Seminary of Cantabria” started using the building as their headquarters. The building was built by Cosme Antonio Bustamante. There are different elements that characterize the building, like the classic style of its yard, the quadrangular area around its central courtyard, and the stonework construction, work carried out very carefully and under a great perfection, as it can be seen on the facade full of balconies. A bit later, the founder decided to create within the building the School of Latin, in order to serve as a school for children, and as a house for teachers.
3.4. Technical information of the building

The information in table 3, is considered the most important or relevant regarding technical data.

<table>
<thead>
<tr>
<th>Relevant technical data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building orientation</td>
</tr>
<tr>
<td>Number of floors</td>
</tr>
<tr>
<td>Total built area</td>
</tr>
<tr>
<td>Total conditioned area</td>
</tr>
<tr>
<td>% of glazing compared against wall</td>
</tr>
<tr>
<td>Walls thickness</td>
</tr>
<tr>
<td>Walls height</td>
</tr>
<tr>
<td>HVAC’s system</td>
</tr>
</tbody>
</table>

Table 3 Technical information of the building

As said in section 3.1, the building is intended to be a Cultural centre, therefore it consists of a library, two files rooms, two meeting rooms, three toilets and one changing room, one computer laboratory and two rooms for workshops. Obviously apart from them there are rooms dedicated to elevators, energy systems, etc.
3.5. Protection of the building

Before starting the simulation, it’s essential to know the protection under which our building is. Since the building is part of an historical area in the city of Comillas, and it’s considered that it has many important elements for the Spanish Heritage which should be kept, the building has received the highest level of protection, and within this, the highest sublevel.

![Figure 9. Level of protection of “El Espolón”](image)

All this means, as explained when talking about building protection in Spain, that the limitations when trying to modify the building will be greater, and the competent bodies or the offices in charge of deciding the actions allowed, will be much more severe when making a decision.

A way to solve this problem, is to choose and implement measures leading to such a decrease in consumption, therefore the office in charge could not complain about the changes made to the building.
4. Model

Within this section, relevant information related to the use of the software, the collection of the data, and the different scenarios created is gathered.

4.1. Design Builder

Design Builder is an energy simulation software, which allows in an intuitive way, to get all the building information regarding energy, carbon, lighting and comfort performance.

Information as important as: energy consumption, indoor air temperature, humidity, weather data, data regarding heating, cooling and ventilation, CO2 emissions, etc. is provided by the software in order to make easier the study and analysis of the building.

4.2. Using the software

The steps followed when using the software were as follows.

- Firstly, after importing a 2D CAD model of “El Espolón”, the construction of the building was carried out thanks to this information, and also to the technical data provided by the Town hall, regarding materials, height, thickness, activities, etc. Since the building has more than one floor, the construction of each one have been carried out separately, and then, the building is built up putting all these floors together.
- Secondly, once the building was finished, different scenarios have been created and simulated. These scenarios include information of the current building, as well as the measures and new actions that want to be taken to improve the efficiency.

4.3. Data collection

A large amount of data and useful information for this Thesis were gathered thanks to the priceless help of Mr. José María Pérez “Peridis”, who has kindly provided a lot of information. For certain specific data, such as the consumption of the building in recent months, it was necessary to contact the Comillas Council for the information, and it has to
be said that they were very helpful too, sending the information they had regarding these matters. Thanks to this it was also possible to validate the Design Builder Model.

4.4. Assumptions

An important rehabilitation work it’s been carried out over the last months, and due to this, the building hasn’t been opened again yet. Because of this, some assumptions have been necessary.

- It was known the use each room would have, but not the number of people using them. Due to this, the simulation will use average values of “density of people per square metre” provided by Design Builder, depending on the activity of each room.
- There are many devices consuming electricity within the building, such as computer, faxes, photocopy machines, etc. Their exact consumption is not known, therefore an average consumption for these type of devices, provided by Design Builder has been used.
- The opening hours of the centre weren’t know yet, therefore the schedule used for the building was the average of the one used by other similar centres throughout Spain.
- Most of the cost of the different measures to implement are known (for example de LED bulbs aerators, etc.), however, the costs of installation, supplementary materials, etc. is not easy to calculate. This way, it will be assumed that these additional costs represent a percentage of the total cost of each measure. This percentage may vary from one measure to another, however, an average of 20% can be assumed.

4.5. Model Validation

The building is not being used at the moment due to an important structural rehabilitation, however, despite this, the building in terms of energy, it is working (heating and cooling systems are on), so it’s easy to check the annual energy consumption. It has to be taken into account, that there is no people using the building, and that some “high intensity” systems such as computers, lights, printers, etc are switched off. Because of this, the internal load is much lower than in normal conditions. The way to validate the model, it’s been to run a simulation with the building “working” but not being used. By doing this, it’s possible to compare the results obtained, with the annual consumption
that the Comillas Town Hall provided me. The building is using fan coils as heating and cooling systems, along with natural ventilation.

In table 4 it can be observed the comparison between the two consumptions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data provided by the Town Hall</strong></td>
<td>166,6</td>
</tr>
<tr>
<td><strong>Data obtained with Design Builder</strong></td>
<td>149,3</td>
</tr>
</tbody>
</table>

Table 4. Table with information to validate the model.

As can be observed, it could be said that the model is validated, since the deviation between the model and the reality is approximately a 10%. Due to this, from now on it will be necessary to consider that the consumption of the real building for each scenario is about a 10% larger that the consumption obtained thanks to the simulations.

### 4.6. Scenarios

This part will comprise an explanation of the different scenarios developed. It will also try to explain why each scenario was chosen, as well as their main characteristics, and the changes implemented for each one starting from the Baseline scenario. Regarding to the results obtained with Design Builder, they will be presented in section 5 along with their:

- Interpretation
- Explication
- Impact & Viability from an economic and energy point of view

**Baseline**

The Baseline scenario attempts to represent as accurately as possible how the building is today, but considering that the building is already being used. In order to do this, and considering that is known the use that each room will have, average occupancy values according these uses will be implemented. In order to develop it, the information and indications coming from both, the Town Hall and architect Peridis have been followed.
This scenario will be a starting point from which other scenarios will be developed. This means that

- First, when developing the scenarios, they all will be based on this Baseline scenario.
- Second, since all the different scenarios will be compared with Baseline, it will be easier to see the differences in consumption between them, and the energy savings achieved.

Thus, it will be easier to decide which scenarios are most appropriate to implement, taking into account the savings achieved with each one, as well as the expense incurred in the measures associated with them.

The technical characteristics of this scenario are exactly the same as the ones of the current building (see section 3.4), so they will not be explain here again.

**Passive scenario**

This passive scenario will be focussed on improving all those elements separating the indoor comfort zones from the exterior environment.

The reason why this scenario has been developed, it is because after carrying out the research work, the majority of the information sources agreed that it was essential to have a good insulation, in order to reach a high energy efficiency in a building. It was useless to have efficient energy systems if they could not isolate the building from the outside conditions. It should be added that this scenario is based on one of the "pillars of energy efficiency".

The changes made on this scenario, taking as a starting point the baseline, are as follows.

- **Roof surfaces**: a layer of insulation has been added to the roof surfaces. Concretely, a thin layer of polyurethane foam, which allows to reduce the heat lost through the roof.
- **Walls**: the procedure followed has been similar. It has to be said that the exterior part of the walls should not be altered. Therefore, an inner insulating layer has been added, particularly extruded polystyrene, along with a plaster coating. This method of adding an inner insulating layer with a coating is a common technique in Spain, and also allowed in protected buildings.
- **Openings**: the problem is similar as with the walls, the exterior appearance should not be modified. The action considered as the best, it’s been to add interior double
windows instead of changing the current ones. The thickness of the windows is 3mm, with an air gap in between.

- **Infiltration:** although this may not seem a big deal, infiltration is being the biggest problem in our building, and it’s mainly caused by its age. The building is more than 200 years old, and the infiltrations are really high, 3 air changes per hour, measured at 50 Pa, which justify the big heat losses. To prevent this, we have proceeded to seal cracks and joints, which is a simple and effective process, and not very expensive. By doing this, the infiltrations have dropped by a 66%, reaching a normal value within the Spanish territory, 1 air change per hour [22].

**Active Scenario**

This is a scenario based on all those measures that use energy to ensure the indoor comfort conditions.

The decision of developing this scenario has been made because, as well as the previous one, is based on one of the key pillars of energy efficiency, and because some measures within these energy systems, are really easy and cheap to implement. Besides, the energy consumption caused by, for example, the lighting system, was extremely high, and this scenario will try to find a solution for it. The actions taken are as follows.

1. **LED lighting system:** LED’s are in most cases a good option, and in the building taken as an example for this thesis this measure will be even better, because
   - Currently, the lighting systems used are really inefficient. The general lighting is consuming 24W/m², while the task lighting consumes 10W/m². By implementing the LED bulbs, the consumption drops by 75%.
   - This measure has a really reduced impact on those characteristic elements of our building, therefore it is a measure that we should always keep in mind when trying to increase the efficiency of protected buildings.

2. **Flow limiters and aerators:** the consumption of both, cold and hot water in the building is quite large for a building of this type, although it is true that this consumption doesn’t represent a big percentage of the overall. By using flow restrictors in showers, and aerators in faucets, the consumption of this type has dropped by 20%. Although the reduction is not that big, this measure is really positive since it doesn’t affect the characteristic element of the building, and it’s really cheap (see section 5 for economic data).
Sensors scenario

This scenario is based on the implementation of control & automation systems, in order to use the systems only when they are needed, and it’s also based on the third pillar of energy efficiency.

It’s necessary to highlight that in this scenario the measures implemented in the active one regarding water consumption will be kept. The changes made are:

Movement sensors: a system of motion sensors have been implemented, and now, each room has two sensor which switch on the lights when somebody is there. As happened with other measures previously implemented, its impact on the building is almost zero, so it’s a measure to keep in mind when talking about protected buildings.

Although a set of sensors has been implemented, the lighting system is similar as in the baseline scenario.

Final scenario

This scenario is the one considered as the best option, taking into account the constraints faced when working with protected building. In this scenario, all the measures discussed previously in the passive, active and sensors scenarios, are implemented at once, therefore it’s not necessary to explain them all again.

It could be said that this scenario is the result that this thesis has been trying to obtain since the beginning. The results of the simulation of this scenario (shown in section 5) show a really substantial reduction in consumption, through which everyone could reach the conclusion that there is no excuse not to increase energy efficiency in buildings, even when these buildings are protected. This matters will be discussed more deeply over the last section of the Thesis, focused on discussions and conclusions.
5. Results

In this section the data obtained thanks to Design Builder for each scenario will be presented, as well as some economic information regarding the measures implemented. The way to structure this section will be as follows:

A. Graphs regarding energy data and explanation
B. Total consumption and breakdown
C. Implementation costs
D. Advantages and disadvantages

And after all this, a comparison between all of them, regarding consumption, costs, impact, etc.
5.1. Baseline scenario

As follows figure 10 has the most representative thermal data regarding the baseline scenario. In the Y-axis it can be seen the heat gains and losses in KWh.

This is the most representative graph, containing both the heat gains (due to heating systems, activity, lighting, etc.) and the heat losses (due to infiltration, ventilation, etc.). Again, a really negative point is the high heat loss caused by air infiltration (3 air changes per hour). Besides, the consumption during the winter is considerable, as well as the high energy consumption caused by the lighting systems throughout the year. These are the most important things to change in the building.

For more detailed thermal data regarding this scenario, see Appendix 1.
Consumption and breakdown

Table 5. Baseline scenario. Consumption breakdown

<table>
<thead>
<tr>
<th>Consumptions (kWh/m²)</th>
<th>Lighting</th>
<th>102</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooling</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>142</td>
</tr>
<tr>
<td></td>
<td>DHW</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Equipment</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>365</td>
</tr>
</tbody>
</table>

Figure 11. Baseline scenario. Percentage each consumption represent

In table 5 is possible to see how the total consumption is broken down into its main components. Thanks to figure 11, it’s possible to see the percentage that each of them represent, of the overall consumption.

The total annual consumption of this scenario is **510680 kWh**
5.2. Passive scenario

As follow it can be observed figure 12, which shows the same data as Figure 11 for the baseline scenario. It has to be highlighted that thanks to the measures implemented in these scenario the infiltration has dropped by 66%, and consequently the losses caused by it. The envelope it’s been totally improved, and these measures lead to an energy consumption decrease.

Graphs

Figure 12. Passive scenario. Heat Balance, Ventilation and Infiltration

For more detailed thermal data, see Appendix 2.
Consumption and breakdown

Table 6. Passive scenario. Consumption breakdown

<table>
<thead>
<tr>
<th>Consumptions (kWh/m²)</th>
<th>Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>102</td>
</tr>
<tr>
<td>Cooling</td>
<td>78,2</td>
</tr>
<tr>
<td>Heating</td>
<td>28,7</td>
</tr>
<tr>
<td>DHW</td>
<td>38</td>
</tr>
<tr>
<td>Equipment</td>
<td>38</td>
</tr>
<tr>
<td>Total</td>
<td>284,9</td>
</tr>
</tbody>
</table>

Figure 13. Passive scenario. Percentage each consumption represent

This figures show similar information as table 5 and figure 11, but for the passive scenario. The same type of information will be shown in the following scenarios.

Thanks to the measures implemented the consumption has dropped, saving 80 kW/m².

ENERGY SAVINGS
Total annual consumption

22%
400000 kWh
Implementation costs

First of all, it has to be said that it hasn’t been possible to determine the price of reducing the infiltration by sealing cracks and joints, since this varies a lot depending on the windows, walls maintenance, etc. however, after reviewing some papers and checking different webpages, they all agree that the cost of this operation is not high, since the method followed is simple and systematic.

<table>
<thead>
<tr>
<th>Measure implemented</th>
<th>Unitary price</th>
<th>Number of units</th>
<th>Total price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof insulation (Polyurethane foam 5cm)</td>
<td>7 €/m²</td>
<td>431m²</td>
<td>3017€</td>
</tr>
<tr>
<td>Walls insulation (extruded polystyrene 5cm+plaster gypsum)</td>
<td>14€/m²</td>
<td>1400m²</td>
<td>19600€</td>
</tr>
<tr>
<td>Interior windows (double glazed, 3cm and 12 cm gap)</td>
<td>150€/m²</td>
<td>276m²</td>
<td>41400€</td>
</tr>
</tbody>
</table>

Table 7. Passive scenario. Implementation costs.

It will be considered that installation and other additional costs account for an extra 20%, therefore the total cost of this scenario is as follows

\[(3017 + 19600 + 41400) \times 1,2 = 76800€\]

The kilowatts saved thanks to this scenario are 110000 kWh, and the price of the electricity in €/kWh in Spain is 0,153 for a building like ours. This leads to save 16830€ every year.

<table>
<thead>
<tr>
<th>Investment cost</th>
<th>Annual savings</th>
<th>Payback time</th>
</tr>
</thead>
<tbody>
<tr>
<td>76800€</td>
<td>16830€</td>
<td>4,6 years</td>
</tr>
</tbody>
</table>

Table 8. Passive scenario. Economic data.

Advantages and disadvantages

- As an advantage, it’s to be said that even with a payback of more than 4 years, carrying out these measures is worth it, since they need low maintenance, and they last for many years.
- As disadvantages
Achieving sustainability in protected buildings in Spain

- It’s true that only the interior of the façade is modified, however, it’s being altered, and even when adding an interior layer is a common measure, it might be a reason for the body in charge to oppose the works.
- The measures taken could make the building could not be used for a while, since they are big or important enough.

5.3. Active scenario

Figure 14 shows the most important thermal information, and also information regarding ventilation and infiltration for the active scenario.

Graphs

![Figure 14. Active scenario. Heat balance, Ventilation and Infiltration](image-url)
It has to be highlighted the big reduction in lighting consumption, as well as a reduction (not that big) in cooling consumption.

Since the lighting consumption is smaller, the associated heat is smaller too, therefore the heating consumption has increased to offset the heat that is not produced anymore by the lighting systems.

For more detailed energy related data, see Appendix 3.

Consumption and breakdown

<table>
<thead>
<tr>
<th>Consumptions (kWh/m²)</th>
<th>Lighting</th>
<th>21.47</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooling</td>
<td>21.47</td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>182.5</td>
</tr>
<tr>
<td></td>
<td>DHW</td>
<td>27.6</td>
</tr>
<tr>
<td></td>
<td>Equipment</td>
<td>39.2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>292.24</td>
</tr>
</tbody>
</table>

Table 9. Active scenario.

Thanks to the measures implemented, and compared with the baseline scenario, the consumption has dropped, saving 73 kW/m².
Implementation costs

Regarding the bulbs, it’s been needed bulbs with different sizes and intensities, therefore the following prices are for each of those different types.

Regarding the aerators and flow restrictors, the price varies from showers to faucets.

<table>
<thead>
<tr>
<th>Measure implemented</th>
<th>Unitary price</th>
<th>Number of units</th>
<th>Total price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting system-LED’s</td>
<td>24€, 50€, 75€</td>
<td>96, 91, 68</td>
<td>11954€</td>
</tr>
<tr>
<td>Flow restrictors-aerators</td>
<td>5€, 20€</td>
<td>13, 4</td>
<td>145€</td>
</tr>
</tbody>
</table>

Table 10. Active scenario. Implementation costs

Therefore, the total cost of these measures, after adding the 20% of installation is as follows

\[(11954 + 145) \times 1.2 = 14520\€\]

The kilowatts saved thanks to this scenario are 103000 kWh, and the price of the electricity in €/kWh in Spain is 0.153 for a building like ours. This leads to save 15759€ per year.

<table>
<thead>
<tr>
<th>Investment cost</th>
<th>Annual savings</th>
<th>Payback time</th>
</tr>
</thead>
<tbody>
<tr>
<td>14520€</td>
<td>15759€</td>
<td>0.92 years</td>
</tr>
</tbody>
</table>

Table 11. Active scenario. Economic data.

Advantages and disadvantages

- As advantages
  - The payback time is really short, less than a year
  - The new systems are really easy and quick to implement
- As disadvantages
  - The heating consumption is even higher than in the baseline scenario
  - The infiltrations are really big, therefore the losses are really high
5.4. Sensors scenario

As follows, figure 16 shows the most relevant thermal information and regarding fresh air for the sensors scenario.

Graphs

![Graph showing heat balance, ventilation, and infiltration](Figure 16. Sensors scenario. Heat balance, Ventilation and Infiltration)

The results are quite similar as in the active scenario, since aerators and flow restrictors have been kept, and instead of using LED’s to reduce the lighting consumption, a set of sensors have been implemented. However, the decrease achieved is not as large as with the previous scenario. In spite of this, the heat produced by the lights is smaller, therefore the cooling consumption decreases.

For more detailed energy related information, see Appendix 4.
Consumption and breakdown

<table>
<thead>
<tr>
<th>Sensors Scenario</th>
<th>Consumption (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>53</td>
</tr>
<tr>
<td>Cooling</td>
<td>25,5</td>
</tr>
<tr>
<td>Heating</td>
<td>162,7</td>
</tr>
<tr>
<td>DHW</td>
<td>28</td>
</tr>
<tr>
<td>Equipment</td>
<td>39,4</td>
</tr>
<tr>
<td>Total</td>
<td>308,6</td>
</tr>
</tbody>
</table>

Table 12. Sensors scenario.
Consumption breakdown

Thanks to the measures implemented, and compared with the baseline scenario, the consumption has dropped, saving 56 kW/m².

ENERGY SAVINGS

Total consumption

Figure 17. Sensors scenario. Percentage each consumption represent

431000 kWh
Implementation costs

What it was said in the previous scenario regarding the flow restrictors and aerators, also applies to this scenario.

<table>
<thead>
<tr>
<th>Measure implemented</th>
<th>Unitary price</th>
<th>Number of units</th>
<th>Total price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion sensors</td>
<td>10€</td>
<td>46(2 per rooms)</td>
<td>460€</td>
</tr>
<tr>
<td>Flow restrictors-aerators</td>
<td>5€, 20€</td>
<td>13, 4</td>
<td>145€</td>
</tr>
</tbody>
</table>

Table 13. Sensors scenario. Implementation costs.

Therefore, the total cost of these measures, after adding the 20% of installation is as follows

\[(460 + 145) \times 1.2 = 726€\]

The kilowatts saved thanks to this scenario are 79680 kWh, and the price in €/kWh in Spain is 0,153 for a building like ours. By doing this it’s possible to save 12191€ per year.

<table>
<thead>
<tr>
<th>Investment cost</th>
<th>Annual savings</th>
<th>Payback time</th>
</tr>
</thead>
<tbody>
<tr>
<td>726€</td>
<td>12191€</td>
<td>0.06 years</td>
</tr>
</tbody>
</table>

Table 14. Sensors scenario. Economic data.

It’s surprising how, by using the energy only when is needed, it’s possible to save a big amount of energy, and to offset the investment costs in less than one month.

Advantages and disadvantages

- As advantages
  - Strong energy reduction with an investment cost much smaller than in other scenarios.
  - The measures implemented are not aggressive with the building characteristics at all.
- As disadvantages
  - The losses continue to be very important since the infiltration is still 3 air changes per hour.
5.5. Final Scenario

In figure 18, it can be seen, how almost none of the gains or losses account for more than 15000 kWh, which means that the new envelope is avoiding or reducing the losses, and the new energy systems are reducing the consumption.

Graphs

![Figure 18. Final scenario. Heat balance, Ventilation and Infiltration](image)

For more detailed information, see Appendix 5.
Consumption and breakdown

<table>
<thead>
<tr>
<th>Consumptions (kWh/m²)</th>
<th>Lighting</th>
<th>18,4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooling</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>50,46</td>
</tr>
<tr>
<td></td>
<td>DHW</td>
<td>28,5</td>
</tr>
<tr>
<td></td>
<td>Equipment</td>
<td>39,4</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>173,76</td>
</tr>
</tbody>
</table>

Table 15. Final scenario.

Consumption breakdown

Thanks to all the measures implemented in the previous stages, it’s been possible to make the consumption decrease by 191 kW/m².

ENERGY SAVINGS

48%

Total consumption

243000 kWh
Implementation costs

The cost of the measures implemented will be an addition of those of the previous scenarios.

<table>
<thead>
<tr>
<th>Measure implemented</th>
<th>Unitary price</th>
<th>Number of units</th>
<th>Total price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof insulation (Polyurethane foam 5cm)</td>
<td>7 €/m²</td>
<td>431m²</td>
<td>3017€</td>
</tr>
<tr>
<td>Walls insulation (extruded polystyrene 5cm+plaster gypsum)</td>
<td>14€/m²</td>
<td>1400m²</td>
<td>19600€</td>
</tr>
<tr>
<td>Interior windows (double glazed, 3cm and 12 cm gap)</td>
<td>150€/m²</td>
<td>276m²</td>
<td>41400€</td>
</tr>
<tr>
<td>Lighting system-LED´s</td>
<td>24€, 50€, 75€</td>
<td>96, 91, 68</td>
<td>11954€</td>
</tr>
<tr>
<td>Flow restrictors-aerators</td>
<td>5€, 20€</td>
<td>13, 4</td>
<td>145€</td>
</tr>
<tr>
<td>Motion sensors</td>
<td>10€</td>
<td>46 (2 per rooms)</td>
<td>460€</td>
</tr>
</tbody>
</table>

Table 16. Final scenario. Implementation costs.

Therefore, the total cost of all these measures, after adding the 20% of installation is as follows

\[(3017 + 19600 + 41400 + 11954 + 145 + 460) \times 1.2 = 76576€\]

The kilowatts saved thanks to this scenario are 268000 kWh, and the price of electricity in €/kWh in Spain is 0.153 for a building like ours. By doing this it’s possible to save 40955€ per year.

<table>
<thead>
<tr>
<th>Investment cost</th>
<th>Annual savings</th>
<th>Payback time</th>
</tr>
</thead>
<tbody>
<tr>
<td>91891€</td>
<td>40955€</td>
<td>2.24 years</td>
</tr>
</tbody>
</table>

Table 17. Final scenario. Economic data

Even when the investment cost may seem high, the money saved thanks to the reduction in consumption, makes this scenario a feasible option to consider.
Advantages and disadvantages

- As advantages
  - This is the most complete scenario, which allows not only to reduce the consumption in different ways, but also to reduce enormously the losses. Therefore, this is the scenario that best fulfil the requirements of the energy efficiency.
  - The payback time is really short, and this scenario would allow us to have a highly efficient building, and to start saving money just after 2,24 years.

- As disadvantages
  - As happens in the passive scenario, the façade and the roof will be modified internally. Usually this is not a problem, but it might be depending on the competent body.
  - This scenario includes many different measures to implement. This way, a long time could be needed in order to implement them, and it’s also necessary to consider the possibility of closing the building during the works.

5.6. Comparison between scenarios

Although all the data regarding consumptions have been shown in the previous scenarios, here it can be observed the data put together, in order to ease the comparison.

<table>
<thead>
<tr>
<th>Consumptions (kWh/m²)</th>
<th>Baseline</th>
<th>Passive</th>
<th>Active</th>
<th>Sensors</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>102</td>
<td>102</td>
<td>21,47</td>
<td>53</td>
<td>18,4</td>
</tr>
<tr>
<td>Cooling</td>
<td>45</td>
<td>78,2</td>
<td>21,47</td>
<td>25,5</td>
<td>37</td>
</tr>
<tr>
<td>Heating</td>
<td>142</td>
<td>28,7</td>
<td>182,5</td>
<td>162,7</td>
<td>50,46</td>
</tr>
<tr>
<td>DHW</td>
<td>38</td>
<td>38</td>
<td>27,6</td>
<td>28</td>
<td>28,5</td>
</tr>
<tr>
<td>Equipment</td>
<td>38</td>
<td>38</td>
<td>39,2</td>
<td>39,4</td>
<td>39,4</td>
</tr>
<tr>
<td>Total</td>
<td>365</td>
<td>284,9</td>
<td>292,24</td>
<td>308,6</td>
<td>173,76</td>
</tr>
</tbody>
</table>

Table 18. Consumption breakdown. Comparison between scenarios
In table 18, it’s possible to see the data of each scenario regarding their energy systems consumption. In order to make this more intuitive, all this information is gathered in figure 19.

![CONSUMPTIONS (KWH/M2)](image)

**Figure 20. Representation of the consumption of each scenario**

Thanks to Figure 20 it’s also possible to see the behaviour of each scenario in relation to each consumption.

As the last part of this comparison, the next charts will show how the consumption changes from one scenario to another, focusing only on one aspect at once.
As it can be observed in figure 21, the best measure to implement regarding lighting consumption is the LED system, although implementing sensors also leads to good results. Both implemented together get the best result taking into account they barely affect the building characteristics.
Cooling

As it can be observed in figure 22, since the infiltration is much lower in the passive scenario than in the baseline, it’s necessary more energy to cool the interior air. For the final scenario this problem is partly offset by the reduction in heat that previously was produced by the lighting system.

Figure 22. Cooling consumption of each scenario
Heating

Some scenarios have achieved a very big reduction in the energy consumed by each energy system, however their losses are still really big, and due to that the heating consumption increases. This happens for example when talking about the active or sensors scenarios. If a high level of efficiency want to be reached, it’s necessary to improve the envelope properly, even when this may seem not really important considering the Spanish weather conditions. This can be seen in figure 22, in the passive and final scenario, in which the heating consumption is clearly smaller than in the other scenarios.
Figure 24. Domestic hot water consumption of each scenario

The variation seen in figure 24 is caused by the implementation of aerators and restrictors. Although the differences are not really big, these measures have to be taken into account in order to get the best results regarding energy efficiency.

The equipment chart will not be included here, since the difference in consumption between the scenarios is almost insignificant. Besides, if needed, it can be checked in the “general” consumptions graph.
Energy and economic data

Table 19 gathers the information regarding investment cost, money saved annually, and the payback time for the measures implemented within each scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Investment cost</th>
<th>Money saved annually</th>
<th>Payback time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>76800</td>
<td>16830</td>
<td>4,6</td>
</tr>
<tr>
<td>Active</td>
<td>14520</td>
<td>15759</td>
<td>0,92</td>
</tr>
<tr>
<td>Sensors</td>
<td>726</td>
<td>12191</td>
<td>0,06</td>
</tr>
<tr>
<td>Final</td>
<td>91891</td>
<td>40955</td>
<td>2,24</td>
</tr>
</tbody>
</table>

Table 19. Economic data of every scenario

- The infiltration was very high, therefore it’s important to fix this problem, however, since the weather in this part of Spain is not extreme, implementing only passive measures doesn’t lead to really good results, and the investment cost is considerably.
- The active scenario is a really good option, although it might not be realistic, since our building had really inefficient lighting systems, and that’s why the decrease in consumption is so large after implementing the LED system. Therefore these scenario could get much worse results when applying it to different buildings.
- Regarding the results shown in table 19, the sensors scenario seems to be the best option, since it barely modifies the building and the reduction reached is really large considering the investment cost, however, in general terms, this reduction is 4 times smaller than the one achieved thanks to the final scenario, therefore these measures would be a good option if the competent body in charge is very strict, and it doesn’t allow to make any changes in the buildings, not even in the interior parts.
- The final scenario could be considered as the most balanced one, since it achieves a high reduction, which leads to an increase in energy efficiency, and with a payback time not too long. Besides it modifies the façade only internally.
Along the development of the thesis, different information regarding energy consumption has been gathered and calculations have been carried out, however, it’s also important to include relevant information related to CO2 emissions, considering the current problem of pollution and global warming, and how these emissions affect these key aspects.

Nowadays, different experts consider that global warming is almost totally produced by greenhouse gases emission (GHG), and that it will raise the temperature of the Earth between 1 and 6 ºC during this century. According to the United Stated environmental agency [23], CO2 gases account for 57% of global GHG emitted, therefore a perfect way to limit the global warming, and limit the GHG emissions, is by reducing as much as possible emissions of CO2.

Taking as an example the building “El Espolón”, it’s possible to include information regarding CO2 emissions along with the energy information. Table 20 shows information regarding how much CO2 the building is emitting when implementing each scenario.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Consumption (KWh)</th>
<th>CO2 intensity of electricity in Spain (KgCO2/KWh)</th>
<th>CO2 emitted (Kg CO2)</th>
<th>CO2 saved compared to baseline scenario (Kg CO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>510680</td>
<td>0,455</td>
<td>232359</td>
<td>---</td>
</tr>
<tr>
<td>Passive</td>
<td>400000</td>
<td>0,455</td>
<td>182000</td>
<td>50359</td>
</tr>
<tr>
<td>Active</td>
<td>408000</td>
<td>0,455</td>
<td>185640</td>
<td>46719</td>
</tr>
<tr>
<td>Sensors</td>
<td>431000</td>
<td>0,455</td>
<td>196105</td>
<td>36254</td>
</tr>
<tr>
<td>Final</td>
<td>243000</td>
<td>0,455</td>
<td>110565</td>
<td>121794</td>
</tr>
</tbody>
</table>

Table 20. CO2 emissions of each scenario

The building consumes electricity for its systems. The CO2 intensity factor allows to get the emissions associated to a concrete energy consumption. That data has been obtained thanks to a lecture based on life cycle costing and environmental impact [24]. Due to this, by implementing these different scenarios, is not only possible to consume less energy which leads to save money annually, but also to reduce the CO2 emissions achieving this way many benefits associated with it, like helping to reduce the global warming. The reductions are similar in relative terms as the ones reached when talking about energy consumption, therefore the best scenario to implement would be the Final scenario since
it saves more emissions, although as it could be observed in the section “Energy and economic data” the payback time is larger than in other scenarios
6. Discussions and Conclusions

This section will cover important aspects this thesis have been trying to deal with, considering their relation with sustainability, such as decreasing energy consumption, the importance of keeping the heritage, and the economic terms of each of the scenarios proposed. It can be observed that these three aspects are strongly linked with the three elements of sustainability: environmental factors, social factors, economic factors.

![Diagram](image)

Figure 25. Relation between main objectives of the thesis and sustainable development pillars.

6.1. Decreasing energy consumption VS Keeping the heritage of the country

Since these are the two main objectives of the thesis, this might be the most difficult and important discussion.

For several years, concern about the environment has been increasing, and several targets in the European Union have been created, like the famous 2020 targets [25], which aim for example, to increase energy efficiency by a 20% with respect to 1990. It’s obvious that trying to reach this goal is difficult, but even when it cannot be reached, it’s necessary to keep trying in order to go forward.

The problem comes when setting the limit between these two objectives, which depends among other things, on the awareness of the country about "environmental factors" as well as on its interest in preserving the heritage.

In a country like Spain, with so many historic and protected elements, it is expected that the interest in maintaining the heritage as unchanged as possible will be really big. In addition many of these protected elements are fully representative of the country,
causing some areas to be more or less famous, and attracting tourist and visitors from
different places. It has to be said that these tourists want to spend their money on visiting
a perfectly preserved building, and not on a highly efficient building which has nothing to
do with its original appearance.

On the other hand, concern about the environment is growing and it will continue to grow
in the coming years, as a result of everything that is happening in relation to the climate
change.

Due to all this, if it’s considered that today it’s difficult to set the limit between these two
aspects, in the future it could be even more difficult because

- Year after year the problems associated with climate change will be greater, which
will lead to greater awareness with anything that can reduce the causes of this
phenomenon. This might suggest that the balance will tip towards decreasing the
energy consumption side, leaving the aspect of “trying to keep the Heritage
unchanged”, more unprotected.

- However, it’s also true that year after year these protected buildings get older, and
their meaning and importance to the heritage of the country are even greater.
Besides, if the competent bodies allow to make changes in these buildings over the
years in order to decrease the energy consumption, even when these changes are
small, the characterization and singularity of the building may be seriously
compromised. This may have the effect of tipping the balance in the “Keeping the
heritage” favour, in order to maintain the heritage of the country for many more
years.

It should be noted that luckily, in the future, there will be new methods and systems to
increase the efficiency, and less aggressive with buildings than the current ones, as well as
new ways to make these buildings look intact, and unaltered over the years. If this
happens, the fact of having to establish a boundary between increasing efficiency and
maintaining the heritage would be a minor thing, and thus, it would be easier to achieve
energy goals without damaging the representative elements of the country.

Lastly, it is likewise important to note that where to set this limit, either today or in the
future, will depend greatly on the competent body in charge, and if it pays more attention
to reduce contaminants and energy consumption or to keep the heritage. Therefore
something that is unlikely to change, it’s the need to show in advance the improvements
that could be achieved in terms of energy thanks to the measures proposed, but obviously
trying not to alter the building, so that it’s possible to convince the competent office.
6.2. Decreasing energy consumption VS Expense incurred

As happened in the previous section, within this one it would be also necessary to set the limit between both aspects, trying to have a better energy performance, spending a reasonable amount of money.

In the results section it was possible to observe the energy savings of each scenario and the cost of investment due to the measures implemented. The one with the highest performance was clearly the “sensors scenario”, since the investment required was really low, while the reduction achieved was considerable. However, one must ask whether this "reduction in energy consumption" is sufficient, or on the other hand, our goals are more ambitious, and although at a higher cost and with a higher payback, we seek to reduce energy consumption as much as possible, even when the ratio is not that favourable.

This limit between these two aspects will depend among other things on:

- **The building**: in some buildings carrying out cheap measures such as the implementation of the sensors is sufficient to achieve a large decrease in consumption. However, other buildings might need to implements a large number of measures in order to increase their energy efficiency, or the most expensive ones, spending this way a large amount of money.

- **The economic situation**: since, for example, in times of economic downturn, as it’s happening today, it is likely that the society doesn’t feel like spending an important amount of money in decreasing energy consumption, although these measures will eventually pose a savings. What they would prefer, it would be to invest that money in other aspects, such as the stimulation of the economy or social benefits. On the other hand, during prosperous times, it will be possible to invest more money in the cause of increasing efficiency, and this, will make the balance be tipped towards this goal, paying less attention to the amounts of money spent.

- **The awareness of the country about the environment**: although Spain is a country where concern about the environment is growing, is far behind from those countries really focused on these matter like the Nordics. In countries such as Sweden, environmental matters are integrated in the society and everybody cares about them. This way, it’s to be expected that the amount of money spent is larger, therefore the balance is tipped towards reducing the consumption instead of towards saving money.

- **The requirements set by European or World organisms**: over the last years, the main World Agencies have been focused on trying to reduce energy consumption and the emissions, which has led to setting some limits or establishing protocols.
like Kyoto and the 2020 objectives. Due to this, if a country turns out to be far behind from achieving these objectives, it could focus on improving the energy efficiency and reducing the consumption of its buildings without caring about the money, in order to fulfil the requirements and avoid fines. On the other hand, if the country has already fulfil these requirements, it could decide to forget about reducing consumption and emissions, in order to save some money.

6.3. Expense incurred VS Keeping the heritage

This section will cover a discussion between the “social” factor and the “economic” factor of this work.

First of all, it has to be said that an important part of what was said in the previous section also applies here. When there is an economic recession, it´s obvious that the money spent in many different things is cut, and of course one of those aspects is apart from reducing energy consumption, the conservation of the heritage.

In fact, as an example of this, the following article explains how Italy is selling a part of his heritage, islands in this case, in order to offset the effects of the economic downturn [26]. By including this article it´s tried to be shown that if a developed country like Italy is capable of selling its own Heritage, it will obviously be capable of leaving some unprotected some of the protected elements the country has, if by doing this it´s possible to save some money.

On the other hand, it has to be highlighted that the Heritage of the country is owned by all its inhabitants, therefore maybe even when the economic situation is not really good, a inhabitant wouldn´t consider correct to leave the historic elements of its country unprotected, which means saving money while letting the history of your country get spoilt day after day.

Spain is likely to be a perfect example for this discussion. Considering how the situation is right now, most of the people is interested in measures which boost the economy and help the country to overcome this difficult situation, therefore the inhabitants would not allow the Government to spend a large amount of money to maintain the buildings, while other aspects considered more important are neglected. It´s important to note:

- Firstly, what would happen if a very representative building of the country is in a really bad condition? It seems obvious that the Government would spend all the
money needed in fixing the building, but would they do the same with a building not as well-known as the previous one?

- Secondly, what will happen when the society look back, and could realize the bad conditions of certain buildings, which are part of the history of the country, and which will have been caused by the fact of saving a bit of money during some years? Is that worth it?

The next example fits perfectly with all commented about Spain regarding this discussion. [27] The Government wanted to reduce the level of protection of one of the most representative buildings in Madrid, in order to make it easier to be sold to a Chinese millionaire who wanted to modify the building completely. Fortunately, the society discovered what was going on and decided to display an explicit opposition, even when this sale would have brought along a lot of money for the city. Thanks to this, it would still be possible to save this impressive building, therefore more people in the future could enjoy its unique features.

Again, and even when it sounds repetitive, the aim is to find a balance between these aspects, while being logic and consistent. It is really difficult, as it has been show in recent discussions, to find the midpoint between each of these aspects when comparing two of them, therefore more difficult it will be when the three aspects are taken into account at the same time, which is what really happens in real life.
6.4. Comparison with the Swedish system

In table 21 it can be seen a comparison between the Spanish and Swedish system regarding building protection, and the most important aspect to consider when carrying out this duty.

<table>
<thead>
<tr>
<th></th>
<th>Spanish system</th>
<th>Swedish system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of protection</strong></td>
<td>It’s general, based on 3 levels with 2 sublevels each</td>
<td>There isn’t a general regulation protecting a group of buildings</td>
</tr>
<tr>
<td></td>
<td>Each building is governed by the guidelines of its level and sublevel</td>
<td>There are “security rules” to ensure the protection of the Heritage. There are 3 categories</td>
</tr>
<tr>
<td><strong>Level of specification</strong></td>
<td>The general law and criteria vary depending on the level and sublevel of protection</td>
<td>The protection guidelines are chosen specifically for each different building</td>
</tr>
<tr>
<td><strong>Who decides the protection</strong></td>
<td>There is a competent body of each area making decisions regarding the buildings situated within it. However the Government might make or change a decision if needed</td>
<td>This is a duty of The National Heritage Board along with the managing authority, and it’s done specifically for each building.</td>
</tr>
<tr>
<td><strong>Classification criteria</strong></td>
<td>Buildings are classified into different categories depending on their characteristics and value for the country</td>
<td>The system is similar, being the buildings classified according their value under the ordinance 2013:558.</td>
</tr>
<tr>
<td><strong>How to make changes</strong></td>
<td>Making a proposal containing the changes, their objective, and the expected achievements, and then, the competent body will decide if the action can or cannot be carried out</td>
<td>-</td>
</tr>
<tr>
<td><strong>Protection VS changes</strong></td>
<td>Changes will be allowed if the improvements to achieve are considered more beneficial than the possible reduction in the value of the building</td>
<td>-</td>
</tr>
<tr>
<td><strong>Overlapping</strong></td>
<td>There is always some problems and criteria overlapping when applying for a permission to make changes, which slows down the process</td>
<td>-</td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
<td>Hierarchical: the Government and then the competent bodies within each area</td>
<td>Hierarchical: Government, The National Heritage Board, and then the managing authority</td>
</tr>
</tbody>
</table>

Table 21. Comparison between the Swedish and the Spanish system regarding building protection
It has to be said, that the Swedish system is much more concrete than the Spanish one, having each building its specific protection and limitation. This way, it’s easier to know what can be done in every protected building in order to improve its behaviour. Although this is something that could be really useful for the Spanish system, it is necessary to highlight that the number of listed elements in Spain is really large, and thus, the cost of doing this could be much higher than the benefits obtained from it.

6.5 Conclusion

Something that was discussed at the beginning of this thesis when talking about sustainable development, is that it’s useless trying to improve only one or two of its elements. In order to truly reach the goal, it’s necessary to focus on the three aspect of sustainability. Likewise a balance has to be kept when working with listed buildings, trying in all cases to reduce energy consumption, while keeping as unchanged as possible all its characteristic features, and spending a reasonable amount of money considering the situation, the building, and the awareness of the country.

It has to be emphasized that it’s vital to learn all about the building that want to be “improved”, as well as its protection and the body in charge of it, in order to make it easier to come up with the correct measures which allow to reach the objectives and to convince the competent body of their benefits for the society.

Taking all this into account, and regarding the scenarios, two main conclusions can be drawn.

- The sensors scenario is clearly the best one in economic terms. Besides, its impact on the building is really reduced, avoiding this way the problems associated with modifying protected buildings. However, the reduction achieved by implementing it, is small when comparing it with other options. This would be the perfect option if the competent body turns out to be very strict.
- The final scenario is the option that best achieve, at the same time, the objectives. From an energy point a view the reduction achieved is much larger than with other scenarios, and this will also lead to a CO2 emissions reduction. The payback time is not long at all, considering all the savings that will be achieved after that time. Regarding the modifications of the building, its main features have been kept unchanged, therefore this scenario will only be a problem if the competent body is too strict or if we are not able to explain correctly all the advantages that can be gained from carrying out this scenario.
Considering all the problems faced regarding how to classify the building, how to tackle the requirements of its protection, which parts could and could not be changed, the lack of specifications, etc. it would be really interesting for the Spanish system, to develop a model or a system to help the competent bodies to classify each protected element more concretely. This means, that every building should have a document containing all the information about its protection, and the elements which should remain unchanged, as happens in the Swedish system. This will help not only to protect the heritage properly, but also to save costs when knowing exactly what to change.

It would also be useful for this topic, to conduct a study about building protection and how to improve their sustainability in countries like Italy and Portugal, which have similar weather conditions, and are also suffering from and economic downturn, which could make think that they should have similar systems as in Spain. However, it is to note that Italy is a country with one of the most important historic heritages in the World if not the most, therefore some differences may apply to the Italian system.
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http://www.epa.gov/climatechange/ghgemissions/global.html

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Related papers used as references


- A really interesting analysis conducted by the English Heritage office, similar to this work and considering many of the topics this Thesis has been focused on. [http://www.english-heritage.org.uk/publications/energy-efficiency-historic-buildings-ptl/eehb-part1.pdf](http://www.english-heritage.org.uk/publications/energy-efficiency-historic-buildings-ptl/eehb-part1.pdf)

- A study carried out by the Polytechnic of Cataluña regarding the steps that have to be followed in order to make changes in buildings, including protected ones. The problem is that this work is too focused on structural and technical changes. [http://asesoramentotecnico.coag.es/wp-content/uploads/2009/07/gactep.pdf](http://asesoramentotecnico.coag.es/wp-content/uploads/2009/07/gactep.pdf)
Appendix

Appendix 1. Baseline scenario, energy related data.
Appendix 2. Passive scenario, energy related data.
Appendix 3. Active scenario, energy related data
Appendix 4. Sensors scenario, energy related data.
Appendix 5. Final scenario, energy related data.