UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

Energy study of a single-family dwelling and improvement proposal

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POLITECHNIKA BIALOSTOCKA

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Energy study of a single-family dwelling and improvement proposal

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Resumen:

En este Proyecto de fin de grado se estudia el cerramiento térmico, equipos de calefacción, refrigeración y obtención de agua caliente sanitaria de una vivienda unifamiliar realizando su certificado energético. Posteriormente se estudian posibles medidas de mejora para mejorar la calificación anteriormente obtenida. Por último, se estudia y evalúa la viabilidad económica del proyecto de mejora.

Palabras clave:

Energy, efficiency, dwelling, heating, and viability

Politechnika Białostocka

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Final Project Mechanical engineering

Ignacio Domínguez Bachiller

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1. Introduction

The concept of energy efficiency is currently a very important factor when designing from electrical appliances or power tools to homes or industrial buildings. It is defined as the profitability of consumption from the manufacture of a product, as well as the costs derived from electricity consumption, heating, cooling, lighting, etc.
The design of an energetically efficient dwelling is a saving for the homeowner, as well as a benefit to the environment. In this project, an energy efficiency study will be carried out on a single-family dwelling located in the city of Valladolid (Spain). To do this I will make a brief description of the dwelling estimating the average costs for a year of electricity and heating (hot water and radiators), and also perform the energy rating of the home according to the Spanish dwelling energy rating, which qualifies the Dwelling on a scale from letter A to letter G, the latter being the least efficient. This scale counts the kilograms of CO2 per m2. Later I will introduce energy-saving elements such as solar panels, biomass boiler, etc. into the dwelling. To see how they vary the costs previously realized and to see the economic viability of the project of improvement.

In order to do this study I will follow the following guidelines:

- Analyze the situation of the dwelling and its orientation for a better use of hours of light, shadows, etc.
- Analyze the thermal envelope of the dwelling (walls), as well as windows and skylights that, after all, is one of the most important factors in mitigating the heat losses of the dwelling under study.
- Analyze dwelling facilities for domestic hot water supply and heating.

Once this first study is done, solutions will be made to improve the energy rating result. These improvements will cover all types of elements, whether thermal insulation, improvement of the installations or incorporation of new elements that will help in this aspect. I will focus on providing solutions to the issues that cause more energy losses.
I will rely on the Spanish energy regulatory framework to make proposals for improvement.

2. Geographic location of the dwelling

Valladolid is a city located 250 km approximately northwest of Madrid. The climate is considered continental Mediterranean. The average temperature during the summer months is 22º in urban area, somewhat lower in areas of the municipality with higher altitude. This climate is due to its geographical location. Valladolid is in the center of the Duero River Basin, which is surrounded by mountains, which isolates it from the sea, making the climate extremely dry. In the western part there are no mountains so it is for this area where rainfall usually arrives in Valladolid. The north winds are dry and cold, the south winds are hot and humid.

As for the rainfall, they are spread out quite irregularly throughout the year. There is a minimum during the summer months and a maximum in autumn and winter. The annual precipitation is 443 mm and the relative humidity throughout the year is 64%. The most outstanding in terms of temperature is the thermal oscillation that is experienced daily, some occasions of more than 20º. The average temperature is 12.7 °. Winters are cold with frequent fog and frost. Summers are generally hot and dry, with maximum temperatures between 30 ° C and 35 ° C, but mild minimum temperatures, slightly above 14 ° C

Figure 1 Valladolid situation in a Spain´s map

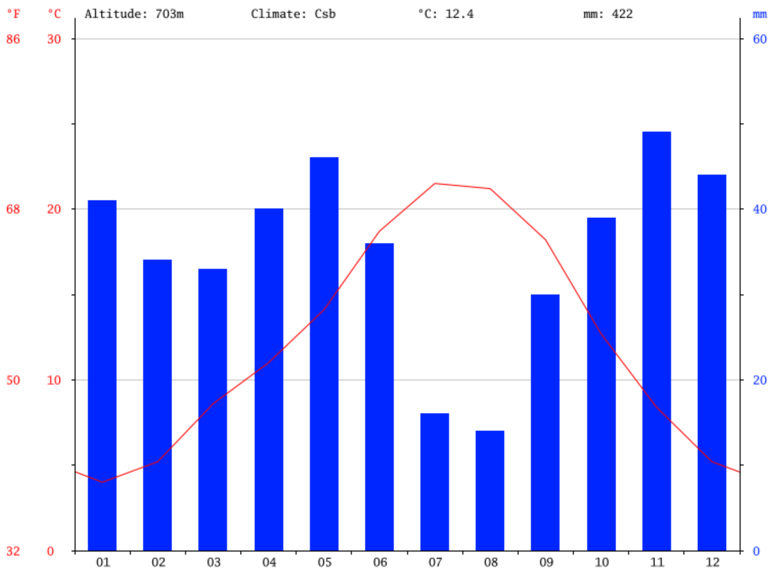


Figure 2 Valladolid´s climogram(Temperature and rainfall)

In the software used, the city of Valladolid is climatically qualified as D2, This rating is based on weather severities in winter (letter) and climatic severity in summer (number)

Tabla D.2a - Severidad climática de invierno

A	B	C	D	E
SCI ≤0,3	0,3 <SCI ≤0,6	0,6 <SCI ≤0,95	0,95 <SCI ≤1,3	SCI>1,3

Figure 3 Climatic severity in Winter

$$SCI = a \cdot Rad + b \cdot GD + c \cdot Rad \cdot GD + d \cdot (Rad)^2 + e \cdot (GD)^2 + f$$

Figure 4 Climatic severity in Winter expression

Where the different parameters correspond to:

- Rad: he average of the accumulated global radiation for the months of January, February, and December [kW h / m2].
- GD: The average winter grades-day on base 20 for the months of January, February, and December. For each month are calculated on hourly basis, and subsequently divided by 24;
- the values of the other parameters are as follows:

a	b	c	d	e	f
$-8,35 \cdot 10^{-3}$	$3,72 \cdot 10^{-3}$	$-8,62 \cdot 10^{-6}$	$4,88 \cdot 10^{-5}$	$7,15 \cdot 10^{-7}$	$-6,81 \cdot 10^{-2}$

Figure 5 Values for the climatic severity in winter expression

Tabla D.2b - Severidad climática de verano

1	2	3	4
SCV ≤0,6	0,6 <SCV ≤0,9	0,9 <SCV ≤1,25	SCV>1,25

Figure 6 Climatic severity in summer

$$SCV = a \cdot Rad + b \cdot GD + c \cdot Rad \cdot GD + d \cdot (Rad)^2 + e \cdot (GD)^2 + f$$

Figure 7 Climatic severity in summer expression

Where the different parameters correspond to:

- Rad: The average of the accumulated global radiation for the months of June, July, August, and September [kW h / m2].
- GD: The average summer grades-day on base 20 for the months of June, July, August, and September. For each month are calculated on hourly basis, and subsequently divided by 24;
- The values of the other parameters are as follows:

a	b	c	d	e	f
$3,724 \cdot 10^{-3}$	$1,409 \cdot 10^{-2}$	$-1,869 \cdot 10^{-5}$	$-2,053 \cdot 10^{-6}$	$-1,389 \cdot 10^{-5}$	$-5,434 \cdot 10^{-1}$

Figure 8 Values for climatic severity in summer expression

3. Compliance with regulations

Before starting, the energy demand of the dwelling will be estimated, for it has been used the basic document of energy saving, specifically its first section: limiting the energy demand
This section is mandatory for newly constructed buildings. Our case is for a dwelling already built, so we will support this section to compare the results of the improvement proposal with those of that section

The energy consumption of non-renewable primary energy of the dwelling must not exceed the limit value Cep, lim, which is obtained by the following expression:

$$C_{ep,lim} = C_{ep,base} + F_{ep,sup} \ / \ S$$

Figure 9 Energy consumption expression

The different meanings of the above expression are:

- Cep,lim: Limit value of non-renewable primary energy consumption for heating, cooling and domestic hot water. This value is expressed in kWh / m2, the surface to be considered is the useful surface of living spaces.
- Cep,base: Base value of energy consumption of non-renewable primary energy, depending on the climatic zone in winter corresponding to the location of the building.
- Fep,sup: Factor corrector by surface of energy consumption of non-renewable primary energy.
- S: Usable living area of the building in m2

For the dwelling under study, a value is obtained:

- Cep,lim : 87,6 $\mathrm{kWh/m2}$.

This value will be used to see if the minimum requirements are met in the dwelling and its proposal for improvement.

4. Software CEX

To elaborate and to make the energy study, I make use of the free software CEX, specifically the version 2.3

This software will give us a great variety of options, which will allow to model the dwelling for its study of a very reliable way, in addition, it has databases very broad in terms of climatic aspects and shadow patterns in a great amount of Locations. A brief outline of the software will be made indicating the most important features.

The data necessary to execute the analyzes are the following:

- General information: Aspects of dwelling such as living space, height, number of plants, and other data, such as location, climatic zone or current regulations, are introduced.
- Thermal envelope: In this option, the different parts of the dwelling are introduced in more detail, such as facades, roofs, windows and the materials used in each part of the building. It also indicates the orientation of dwelling.
- Installations: It is possible to define all the possible installations that can have the dwelling and its characteristics. It ranges from basic boilers for obtaining hot water to mixed boilers or auxiliary equipment for obtaining energy.
- Having already entered this data, we can perform the following analyzes:
- Energy analysis: The program allows us to know a multitude of data of interest such as primary non-renewable energy consumption, carbon dioxide emissions, demands, etc. Separating consumption depending on whether it is: heating, hot water or refrigeration.
- Economic analysis: When making a proposal for improvement in dwelling, having already carried out a first analysis, we can see, introducing previously all the costs of electricity, natural gas, biomass, useful life and cost of equipment and materials, how profitable it can To become that proposal of improvement. This is to be evaluated using the NPV (Net Present Value) concept, which allows the calculation of the present value of a certain number of future cash flows, which are generated by an investment. The methodology consists of discounting at the present moment (ie, updating by a rate) all future cash flows, or determining the equivalence at time 0 of the future cash flows generated by a project and Compare this equivalence with the initial outlay. This discount rate (k) or discount rate (d) is the product result between the weighted average cost of capital (CMPC) and the inflation rate of the period. When such equivalence is greater than the initial outlay, then it is recommended that the project be accepted.
  It is given by the following expression:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \qquad (Ec1)$$

Being:

- Ct: net cash inflow during the period t
- r: discount rate
- t: number of time periods
- Co: total initial investment costs

That is, for the improvement project to be acceptable, the NPV needs to be greater than zero.

5. Constructive analysis and dwelling description

a. Objective of the project

This project has been carried out with the objective of describing all the aspects that have relation with energy subject of the detached dwelling of two plants under study.

b. General description of the dwelling

The property situated in the city of Valladolid (Spain) is a villa designed for a family. The villa consists of 2 habitable floors and a loft: ground floor at street level and top floor. It does not contain underground plants. It is located in a plot away from other buildings so it will not affect the study the shadows that could produce other buildings on the dwelling.

Figure 10 Front view of the dwelling

i. Constructive description of the dwelling

The first plant of 2.7 meters high (108.6 m ^ 2) is composed of:

Area distribution of the first floor	
FIRST FLOOR	AREA(m2)
garage	32,1
living room	42,1
hall	4,3
bathroom	1,5
kitchen	10
living room 2	11,4
bathroom 2	6,2

Figure 11 First floor plan

Second plant of 2,7 m high (67,4 m ^ 2):

Area distribution of the second floor	
SECOND FLOOR	AREA(m2)
Room 1	11,4
Room 2	13,4
Room 3	15,1
Living room	13
Bathroom	7,2
Auxiliar room 1	3,3
Auxiliar room 2	4

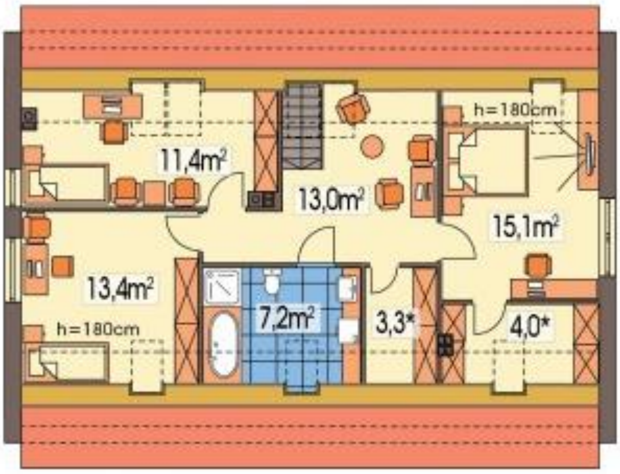


Figure 12 Second floor plan

The thermal envelope consists of all enclosures separating living spaces from the outside environment (air, ground and other buildings) and all interior partitions that limit living spaces with non-habitable spaces that in turn are in contact with the Outside environment.
The outer walls of the first floor of the dwelling are formed by a layer of calcium silicate 24 cm thick and another layer of polystyrene 14 cm. The interior walls are composed of an 18 cm layer of silicate. For its part, the second floor of the dwelling is at the height where the deck is already installed, so for the second floor, we will use the thermal properties of the dwelling in the front wall and back wall and the thermal properties of the Exterior walls of the ground floor for the two side walls. The thermal conductivity of these two materials used are as follows:

- Expanded polystyrene: 0,04 W/mºC
- Calcium Silicate: 0,051 W/mºC

The dwelling cover will have a slope of 30º with unidirectional forging, the estimated thermal transmittance of the deck is 2.56 W / m2K.
The boiler installed in the dwelling is a mixed boiler of heating and sanitary hot water with a power of 24 kW, medium insulation and a combustion efficiency of 90%.
The distribution of windows according to the 4 walls of the dwelling will be:

- Front wall, northeast orientation:
  - Window 1(3 units): 1x0,5m
  - Window2 (1 unit): 0,5x0,5m
  - Window 3(1 unit):0,8x1,5 m

- Rear wall, southwest orientation:
  - Window 4(3 units):1,3x1m
  - Window 5(2 units):3x2m

- Side wall northwest orientation:
  - Window 6(2 units): 2x1,8m

- Side wall, southeast orientation:
  - Window 7(1 unit):4x0,5m

  - Window 8(1 unit):0,8x1,2m

All these windows will initially be simple glass with metal frame (15% surface area of the window) without breaking thermal bridge, which gives thermal characteristics of:

- Alpha Frame Absorbance: 0.75
- Overall heat transfer coefficient: 5.7 W / m2K

The front of the dwelling is oriented towards the northeast, for a greater use of the sunlight. This decision is very important as it can mean an energy saving of up to 70%. This decision has been reached because in the town of Valladolid in summer, when orienting the dwelling towards the northeast we will have sunlight all morning and at dusk. This benefits our dwelling since the summers in Valladolid are very hot in the central hours of the day and fresh in the early hours of the morning and at dusk. This is going to hurt the dwelling in winter since it will be a great expense of heating, this we can solve it for example with a good insulation or with some windows of quality.
At the end of the document are the main plans of the dwelling.

ii. Installation description of the dwelling

The dwelling will have a mixed boiler for heating and domestic hot water. It is a boiler of the trade mark CENTRAL HEATING, with a power of 24 kW.

Figure 13 Photo of the dwelling boiler

This image shows the technical specifications for our model:
SYSTEM 24.

	SYSTEM 15	SYSTEM 18	SYSTEM 24	SYSTEM 30
Height mm	700			
Width mm	395			
Depth mm	278			
Weight (packaged) kg	34.1			
Max installation weight kg	27.7			
CH output (kW) min/max @ 70°C	4.8 - 15.0	4.8 - 18.0	4.8 - 24.2	6.1 - 30.3
CH output (kW) min/max @ 40°C	5.1 - 15.9	5.1 - 19.1	5.1 - 25.6	6.4 - 31.0
DHW output (kW) max	n/a			
DHW flow rate l/min. 35°C rise	n/a			
SEDBUK rating (2005) %	91.1	91	91	91.1
SEDBUK rating (2009) %	89.3	89.2	89.5	89.6
NOx classification	CLASS 5			
Adjustable to LPG	No	No	No	Yes

Figure 14 Technical data of the boiler

This natural gas boiler will cover all demand for heating and domestic hot water, will have a combustion efficiency of 90%. It is an old boiler with not too good insulation.

c. Theoretical fundamentals and calculation of global coefficient of heat transfer

This calculation will be used for the parts of the dwelling that make up the external enclosure of the dwelling and the inner walls, as well as the thermal bridges that are in the outer walls like the pillars, boxes of blinds, etc. The concept that will most import us in the thermal transmittance or global coefficient of heat transmission, which is represented by the letter U. It is defined as the heat that flows per unit of time and surface, transferred through a constructive system as A wall, which may be formed by one or more layers of material when there is a thermal gradient of 1 C or Kelvin between the two atmospheres that separates them. In the international system it has the following units: W / m2K or W / m2 C

Its calculation follows the following expression:

$$U = \frac{1}{R_t} = \frac{1}{Rs_i + R_1 + R_2 + \ldots + R_n + Rs_e}$$

Figure 15 Expression of the global heat transfer coefficient

Being:

- Rt: Global thermal resistance.
- Rsi: Internal surface heat resistance (m2·K/W)

- Rj: Thermal resistance of each of the layers forming the element (m2·K/W)
- Rse: External surface heat resistance (m2·K/W)

The thermal resistance of each layer forming the wall or the wall follows the following expression:

$$R_j = \frac{e_j}{\lambda_j}$$

Figure 16 Expression of the termal resistance of a flat layer of material

Being:

- Ej: Thickness of each layer in m
- **λ**: Thermal conductivity of layer jW/(Km).

The calculation process will be as follows: it starts by calculating the energy needed to supply each of the rooms in the dwelling to maintain a comfort temperature, with this power must compensate for heat losses through the walls and Windows. These losses are a function of the overall coefficient of heat transfer, the areas of walls and windows and the difference in temperature between the interior and exterior.

i. Calculation of the global heat transfer coefficient for the external wall

Distribution of materials of the external wall		
External wall	thickness(m)	conductividad(W/mK)
Calcium silicate	0,24	0,04
Expanded polystyrene	0,14	0,051

Thermal Resistance Calcium Silicate:

$$R1 = \frac{0{,}24}{0{,}04} = 6\ \frac{m^2K}{W} \quad (Ec2)$$

Thermal resistance expanded polystyrene:

$$R2 = \frac{0{,}14}{0{,}051} = 2{,}74\ \frac{m^2K}{W} \quad (Ec3)$$

Coefficient global heat transfer:

$$U = \frac{1}{6+2{,}74} = 0{,}1144\ \frac{W}{m^2K} \quad (Ec4)$$

ii. Calculation of global heat transfer coefficient for the interior wall

Distribution of materials of the internal wall		
Internal wall	thickness(m)	resistance(W/mK)
calcium silicate	0,18	0,04

Thermal Resistance Calcium Silicate:

$$R1 = \frac{0{,}18}{0{,}04} = 4{,}5\ \frac{m^2K}{W} \quad (Ec5)$$

Coefficient global heat transfer:

$$U = \frac{1}{4{,}5} = 0{,}222\ \frac{W}{m^2K} \quad (Ec6)$$

iii. Calculation of the global coefficient of heat transfer for windows

The existing windows in our dwelling are treated with old windows, with metal frame. Metals are bad thermal insulation, and they are single-glazed windows, so the overall coefficient of heat transfer is very high for windows in our home. This is going to be a very important factor when it comes to seeing thermal efficiency because according to studies made by manufacturers like REHAU, up to 47% of energy losses occur through windows.
The overall coefficient of heat transfer for windows in our home is:

$$U = 5{,}7\ \frac{W}{m^2K} \quad (Ec7)$$

When comparing this coefficient with either of the two types of walls (exterior or interior) you can see at a glance that one of the most important factors in our home to improve the starting results will be to improve the insulation of the windows.

iv. Global coefficient of heat transfer for the roof

The roof of our dwelling, will have an inclination of 30º and a total surface of 125 m ^ 2
The cover shall be formed by a one-way forged concrete reinforced concrete on which a layer of properly insulated tiles
The overall coefficient of heat transfer will be:

$$U = 2{,}56\frac{W}{m^2K} \quad (Ec8)$$

v. Global coefficient of heat transfer for the floor

We will have two different types of floors: the ground floor and the first floor. They will be different for our dwelling.
In the ground floor we will have that the global coefficient of heat transfer has a value of:

$$\mathrm{U} = 0{,}84\frac{\mathrm{W}}{\mathrm{m^2K}} \quad (Ec9)$$

In contrast, the first floor of the dwelling is made of other materials so the coefficient will be different, in this case will be worth:

$$U = 0{,}34\frac{W}{m^2K} \quad (Ec10)$$

Seeing the starting values. We will see that the design of the floors is not very efficient. As we already know the transfer of heat by conduction is expressed by the Law of Fourier:

$$q = UA(\Delta T)_{total} \quad (Ec11)$$

Being:

- U: Global coefficient of heat transfer
- A: Total area of heat exchange
- $(\Delta\mathrm{T})_{\mathrm{total}}$: Total temperature variation between the two environments.

So when the dwelling was designed it would have been more convenient to have put the floor of the ground floor on the first floor and vice versa, since on the ground floor the overall heat transfer coefficient is higher and the temperature difference between the Dwelling and the ground is much greater than that between the first floor and the ground floor of the dwelling. This will cause greater losses at the beginning (before the improvement) due to poor layout of the floor of the dwelling.Después de haber visto y analizado los cerramientos de la vivienda, a simple vista se puede ver los dos puntos básicos sobre los que hay que centrar atención a la hora de mejorar:

- Windows: these are windows without double glazing, with a large surface area and aluminum metal frame, which is synonymous with a high overall heat transfer coefficient.
- Floor: poor floor layout will cause high losses, in part due to the large area of heat transfer 108.6 m ^ 2

In the next section, the energy efficiency study will be carried out for the initial dwelling where we will analyze the results obtained technically and make a study of the possible solutions that we can introduce to improve the energy rating result.

6. Energy efficiency study for the single family dwelling

This section explains the analysis performed on our home, as well as the interpretation of the results obtained.

a. Entering base case data

I started by entering the general data of my home in the software used, explained previously in section 3.

In the following image we can see the general data.

Figure 17 General data of the dwelling

In this panel of the program, the most general aspects of dwelling are introduced, such as the useful surface area (176 m 2), the number of floors (2), the ventilation of the building (0.63 r / h) (112 L), the regulations to be applied (CTE 2013, Tecnichal edification code 2013) and data on the location of the dwelling (Valladolid) and its climatic zone (D2) are also introduced.

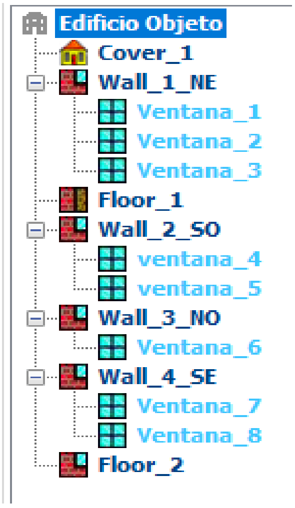


Figure 18 Scheme of the termal envelope of the building

Later I introduced the data that define the thermal envelope of the dwelling: walls, walls and their orientation, roofs, windows and floors. All of them with their corresponding thermal data.

In this image you can see the scheme of enclosures of the dwelling. Where we have the dwelling cover, the 4 walls that make up our dwelling with its corresponding windows and floors on both floors.

Afterwards, I have entered the data of the installations (the aforementioned boiler):

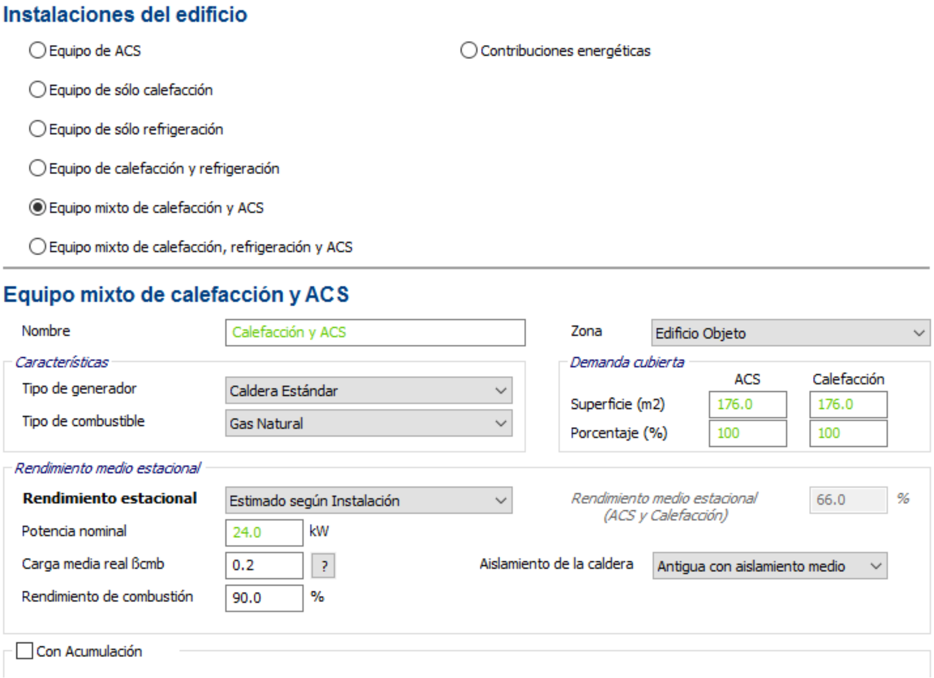


Figure 19 Technical data of the boiler

The type of installation is specified, in our case it is a mixed boiler of heating and sanitary hot water. It uses natural gas as fuel. It satisfies 100% of the demand. It also specifies boiler power (24 kW), average real load (0.2) that allows to know the average load factor seasonally for installations with several heat generators working simultaneously. The boiler has a medium insulation, an option that we can also introduce in the software

b. Analysis results

After entering all the necessary data to make the analysis, we can obtain the result of the energy certificate. I have used the qualification system imposed by the Ministry of Dwelling and Town Planning together with the Ministry of Energy of Spain. This certificate provides information about the energy efficiency of the home, allowing the user to make a decision when buying a home from an efficient point of view. Homes qualified using this method will have a label with colors and letters ranging from letter A to G, with G being the least efficient. We can make a division where the letters A and B mean excellent efficiency with a large increase in investment made. The letters C and D mean a standard efficiency with a moderate increase of the incersion made. The letter E would be equivalent to the current standard of construction marked by law (art 4.1.10 OGUC 2007). The letter F would be equivalent to dwelling built with technical requirements set by the OGUC regulations of 2001. Finally, a G means that the dwelling has been built without thermal extinguishments.
The main factors to be included in an energy rating certificate are the following:

- Thermal insulation of ceilings
- Window type (single glass, thermo panel, triple panel)
- Thermal insulation of walls, doors and floors exposed to the exterior
- Solar panels for hot water heating and heating
- Photovoltaic panels for lighting

- Efficient heating and domestic hot water equipment
- Protective films in glass and windows
- Window shading elements
- Orientation of windows relative to the sun.

When performing the energy rating for the home under study, the software shows the following results:

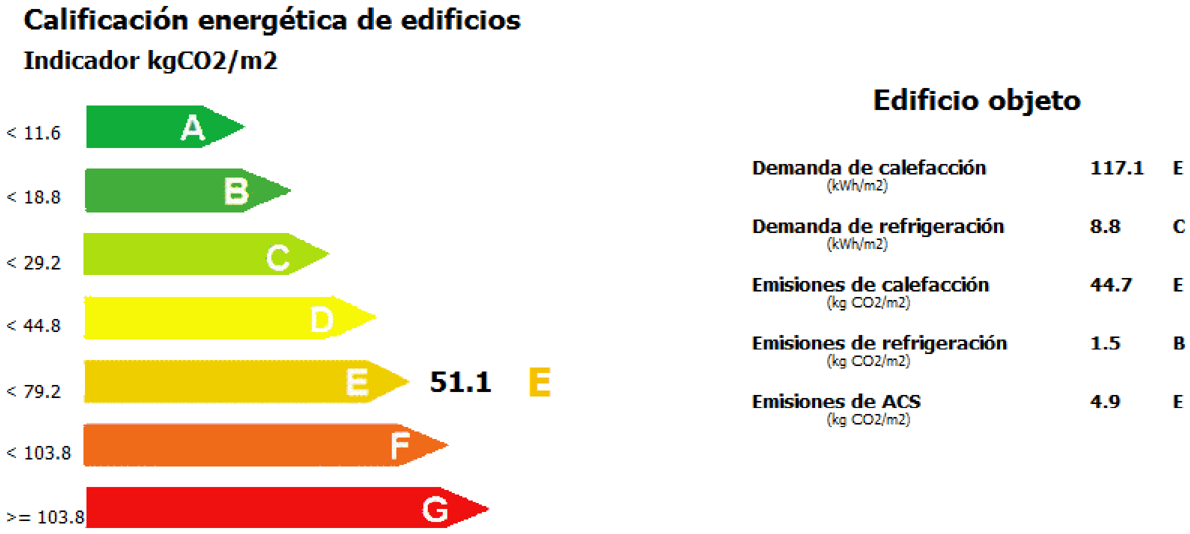


Figure 20 Energy enhancement of the dwelling

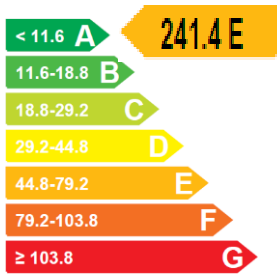
An E rating has been obtained, which complies with the standard of the law of 2007 (art 4.1.10 OGUC 2007). Today, this rating would be very negative for a newly built home. This scale quantifies the kilograms of CO2 per m 2. In addition to giving us this value. It quantifies the demands of dwelling. We obtain the following results:

- Heating: 117,1 kWh/m^2 (E)
- Refrigeration: 8,8 kWh/m^2 (B)
- Heating emissions: 44,7 kWh/m^2 (E)
- Refrigeration emissions: 1,5 kWh/m^2 (B)
- Heat wáter emissions: 4,9 kWh/m^2 (E)

As you can see, these results are very deficient from an energetic point of view. Except for the demands and the emissions of refrigeration, this is because we do not have refrigeration equipment due to the geographical location of the dwelling. Looking at these results we should try to reduce the consumption of heating, this is the same as isolating a more convenient dwelling.

On the other hand we obtain the following results.

Energy rating of the building in non-renewable primary energy-		
Type	primary energy(kWh/m2 year)	
Heating	209,56	E
Sanitary hot water	23,16	E
refrigeration	8,63	C
illumination	-	-
Global		241,4 E



In this table we can see the non-renewable primary energy consumption, where clearly the heating is going to be what causes greater consumption. A score equal to that obtained by taking into account the kg CO2 / m ^ 2 is obtained.
In section 3 of this project, the non-renewable primary energy limit established by the regulations used is established. This value has a limit value of 87.6 kWh / m ^ 2. So by comparing these results, you can see that the rules are not met.
The partial breakdown of energy demand for heating and cooling:

- Heating: 116.2 kWh/m^2. (E)

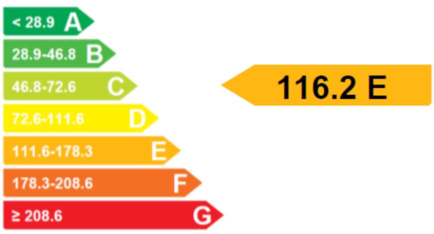


Figure 21 Energy qualification of the dwelling heating

- Refrigeration: 8,8 kWh/m^2. (C)

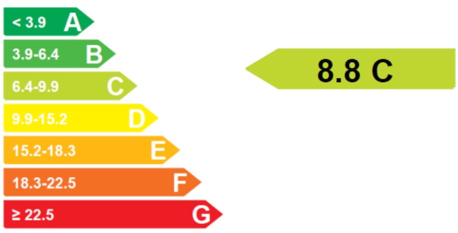


Figure 22 Energy qualification of the dwelling refrigeration

Seeing these results, it can be seen that the initial design of the dwelling has been very deficient due to the high consumption, mainly in heating. Following the points mentioned above. In the process of improving dwelling, there will be emphasis on the enclosures of the dwelling. Particularly in those with a higher coefficient of heat transfer and greater area. These can be for example the crystals and the dwelling cover.

The total annual consumption of the dwelling is estimated at 16966.4 kWh. This is approximately equivalent to energy costs of € 1632.33 per year. These expenses can be easily reduced by modifying enclosures and including some additional equipment such as solar thermal panels. After the incorporation of the new equipment, the energy analysis of the same dwelling will be carried out again and we will compare the data obtained with the base case. Apart from that, we will see the economic viability of the improvement project.

7. Improvement measures for single family dwelling

In light of the results obtained with the CEX software, we will have to make a series of modifications in the dwelling in order to improve the qualification of the energy certificate until a favorable result, that is why a rating between an A and a B. We will also try to comply With the objective marked by the legislation of the primary non-renewable energy limit value of 87.6 kWh / m2.

The main improvements that can be introduced in the dwelling are:

- Addition of thermal insulation in enclosures, roofs and roofs. This is a relatively inexpensive and durable measure although with a complex installation.
- Modification windows: It is a somewhat more expensive, but effective and lasting measure. In this aspect we can obtain an important improvement since the windows of our dwelling of departure are of metallic frame (aluminum), this means that they conduct well the heat so it dissipates much heat to the atmosphere, in addition, they are of simple glass (without Air chamber in between) so the overall coefficient of heat transfer will be very high. We will have a great range of improvement since the glassware of our dwelling supposes a great percentage of the external enclosure of the dwelling.
- Thermal insulation in floor: This measurement is also inexpensive although with a high installation cost, although it is a measure of high durability
- Roof insulation: this measure, like other insulation related ones, is inexpensive and durable, although the installation cost in this case is lower.
- Installation of new equipment: This section ranges from changing the boiler to a more modern and efficient one, to the purchase and installation of equipment such as solar thermal panels, photovoltaic solar panels, biogas boilers, wind turbines and other renewable energy equipment

Analyzing the different options and looking at the data we get from the starting dwelling, I decided to improve the following aspects of dwelling:

- Improvement in insulation of the roof: Seeing the overall coefficient of heat transfer of the roof of the starting dwelling (2.56W / (m ^ 2 K)) and that it is a large surface, we can make with little money a Important improvement. An expanded polystyrene insulation of 0.21 m thickness has been installed. This new layer introduces a thermal resistance of value:

$$R2 = \frac{0,21}{0,051} = 4,154\ \frac{m^2K}{W} \quad \textit{(Ec12)}$$

So the new heat transfer coefficient will be:

$$U = \frac{1}{0,390625+4,154} = 0,22\ \frac{W}{m^2K} \quad \textit{(Ec13)}$$

As you can see, this measure is going to reduce by more than 95% the overall coefficient of heat transfer

- Improvement in soil insulation: It would be essentially in the ground of the ground floor that is the one that is in contact with the ground. The coefficient of heat transfer was not very high (0.84W / (m ^ 2K)), but it is a very large area that covers the ground floor, the temperature difference between the interior of the dwelling and The terrain will be very high. So the losses due to the ground floor are important.

A layer of rock wool of 7cm (thermal conductivity: 0.04W / mK) has been introduced for the improvement, this will introduce a thermal resistance of value:

$$\mathrm{R2} = \frac{0{,}07}{0{,}04} = 1{,}75\ \frac{\mathrm{m^2K}}{\mathrm{W}} \quad \textit{(Ec14)}$$

So the new overall transfer coefficient for the floor of the ground floor will be:

$$U = \frac{1}{1{,}1904+1{,}75} = 0{,}34\ \frac{W}{m^2K} \quad \textit{(Ec15)}$$

- Improves crystals. A double crystal will be introduced in all the windows, this will make the global coefficient of heat transfer half. This aspect could be further improved but the price would increase greatly. Another possible solution in this aspect, would be to change the metal frame by one of PVC as it isolates more, although as I mentioned before, this would trigger the price of improvement. So that only the measure of installing a double crystal will be carried out.

Therefore when introducing a double crystal, the thermal resistance will be double, ie the overall heat transfer coefficient will be:

$$U = \frac{1}{0{,}175438+0{,}175438} = 2{,}85\ \frac{W}{m^2K} \quad \textit{(Ec16)}$$

- New definition of installations: Installation of solar thermal panels, which help supply hot water and heating. At the time of installation of these equipments, it is necessary to take into account the orientation of these solar panels and their inclination. I have chosen panels without solar trackers, an element that increases the performance of these equipments but that increase the price considerably. The inclination of these panels will be of 30º, this orientation is the optimal one for the greater use of the sunlight in winter when the hours of light are scarce, as in summer when the important hours of sunlight focus in the central hours of the Day and in the evening. A total of 3 plates will be installed

8. Energy efficiency study of the dwelling improvement proposal

After introducing all the improvements of the dwelling in the software. I proceed to do the analysis. The economic feasibility of the improvement project will then be analyzed, compared and analyzed.

In the following image you can see the improvement measures, with the costs and useful life of the different measures.

Improvement measures		
Type of measure	useful life(years)	Cost(€)
Installations(solar panels)	23	2000
Thermal insulation of the floor	50	510
Improvement of the windows	15	4500
Thermal insulation of the roof	50	720
Total		7730

When performing the analysis, the first result that the program offers us is the new energy rating, which we see that has improved significantly, to very good levels. We obtained a grade of 18, corresponding with a letter B, in the case of starting we had a letter E, so the improvement is considerable.

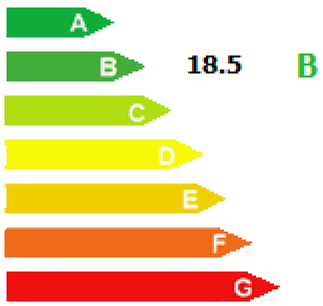


Figure 23 Energy qualification of the dwelling after the introduction of improvements

Subsequently the software is made a chart of heating, cooling and domestic hot water in terms of demand and emissions.
Chart:

Saving of the improvement measures			
Results	Measures for improvement	Base case	saving
Heating demand	43,5 B	117,1 E	62,90%
Refrigeration demand	8,1 C	8,8 C	8,30%
Heating emissions	13,3 B	44,7 E	70,30%
Refrigeration emissions	1,3 B	1,5 B	8,30%
Heat water emissions	3,9 D	4,9 E	20,00%
GLOBAL EMISSIONS	18,5 B	51,1 E	63,70%

As you can see in the chart, it has improved in all aspects. Mostly in heating and domestic hot water, since the dwelling hardly makes use of refrigeration equipment. The most important factor was the saving in heating, which was where it was spent more annually. This will mean an overall saving of 63.70%

In general, the partial ratings are going to improve considerably, this indicates that the reform supposes to make the dwelling much more efficient: less heat loss, better insulation, use of sunlight with renewable energy technologies.

Results of the kilograms of CO2 per square meter have also been obtained: 18,3

Expression of the global heat transfer coefficient

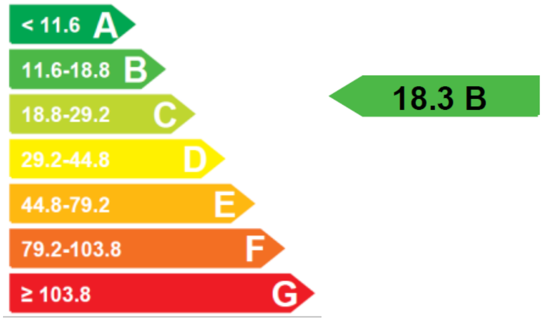


Figure 24 Energy rating of kgCO2/(m2*year)

We see that the previously obtained result of 51.13 kgCO2 / (m ^ 2 year)

The value of nonrenewable primary energy has also improved considerably: 88.13kWh / m ^ 2 year

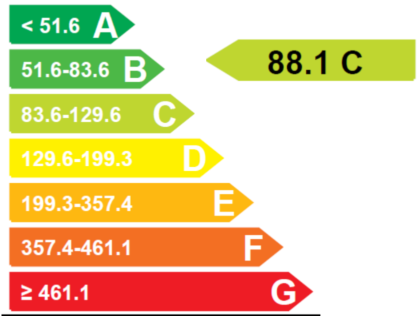


Figure 25 Energy rating of kWh/(m2*year)

This value is in which we had to fix to see if we fulfilled with the regulation that we have used. The limit value we had to respect took a value: Cep, lim of: 87.6 kWh / m2 .. The value obtained is slightly higher than that dictated by the regulations but compared to that obtained in the first study, we will give as Valid since the old one has a value of: 241,4 kWh / m2. This represents a decrease of 63.5%.

The following table shows a breakdown of the different consumptions and the saving that implies in the annual consumption of the dwelling.

Summary of savings								
Indicator	Heating		Refrigeration		Heat water		Total	
-	Value	Saving	Value	Saving	Value	Saving	Value	Saving
Final energy consumption(kWh/m2*year)	51,76	70,60%	4,06	8,10%	15,57	20%	71,39	64,30%
Primary non-renewable energy consumption(kWh/m2*year)	61,59	70,60%	7,93	8,10%	18,53	20%	88,06	63,50%
CO2 emissions(kgCO2/(m^2 year))	13,04	70,60%	1,34	8,10%	3,92	20%	18,31	63,90%
demand(kWh/m2*year)	42,7	63,30%	8,12	8,10%	-	-	-	-

Analyzing the table, we can see that the heating is where we have achieved greater savings, this is of great importance since it is where more is spent in the home.
As for refrigeration, we get a small saving but it will not be of great importance due to the low consumption.
In hot sanitary water we do not get the same saving level as with heating although the saving achieved can be considered significant due to consumption.
The overall balance is finally a savings of around 64%. This figure is very positive. There has been this room for improvement since the design of the starting dwelling was very poor since it was an old building, where it was tried to save as much as possible the construction cost of it. Although as we can see, the money you save in building an energy efficient home, is going to spend on heating the dwelling and the supply of domestic hot water for the most part. The final result after the introduction of improvements is very positive (B), dwelling has been highly energetic. Now we have to evaluate the costs of improving dwelling and if this improvement process is profitable.

9. Economic evaluation of the dwelling improvement process

When making this improvement process, we have to check beforehand that this is a profitable investment. The savings experienced is 64%. The new annual consumption will be 3715 kWh. The approximate price of the annual invoice will be € 357.41 in natural gas, instead of the 990 previously required.
However, the cost of the improvement measures is € 7730 (solar panels, insulation, labor, etc.).
We will evaluate through the concept of NPV explained above the viability of the project. The NPV (Net present value) will evaluate all the costs that have to be taken into account and tell us, the money saved and also the years necessary to amortize the project or to start making profits from our investment.
NPV expression

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \quad (Ec17)$$

Being:

- Ct: net cash inflow during the period t
- r: discount rate
- t: number of time periods
- Co: total initial investment costs

We will only take into account for our studio the expenses derived from the invoices and the investment in the Improvement Project.
After performing the calculations, we obtain:

Years of amortization	NPV(€)
17,6	>0

As the investment is profitable, it will take almost 18 years to amortize the investment. What will be obtained later will be benefits for the owner of the house. The materials and facilities acquired for the improvement present high durability. The equipment that will need to be changed before will be the windows that have a useful life of 15 years. The thermal solar panels have an estimated life of 23 years assuming a correct maintenance of the same. On the other hand the insulators have a half-life of 50 years, since they often present problems with humidity or deterioration over time.

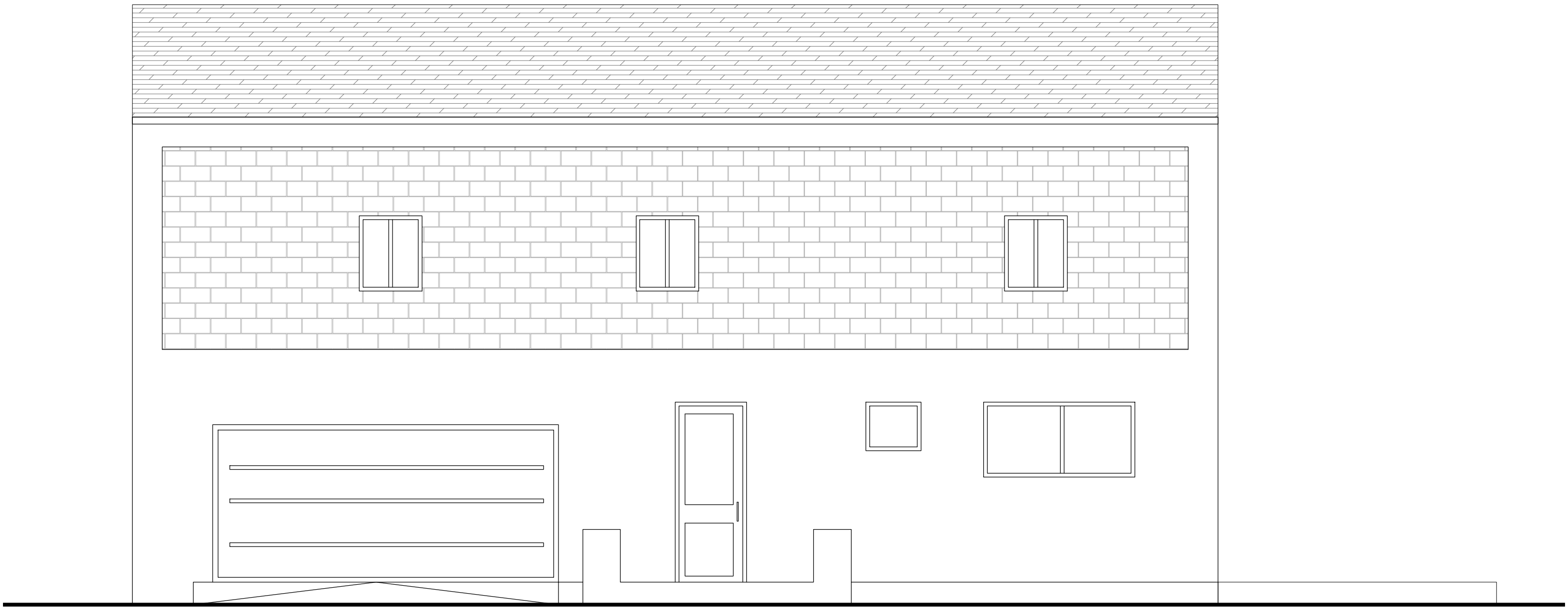
10. Conclusion

In view of the results obtained both at the energy level and at the economic level. It can be deduced that the improvement of housing is totally worth it. The starting house had a very poor design, so we have achieved this percentage of improvement so high.

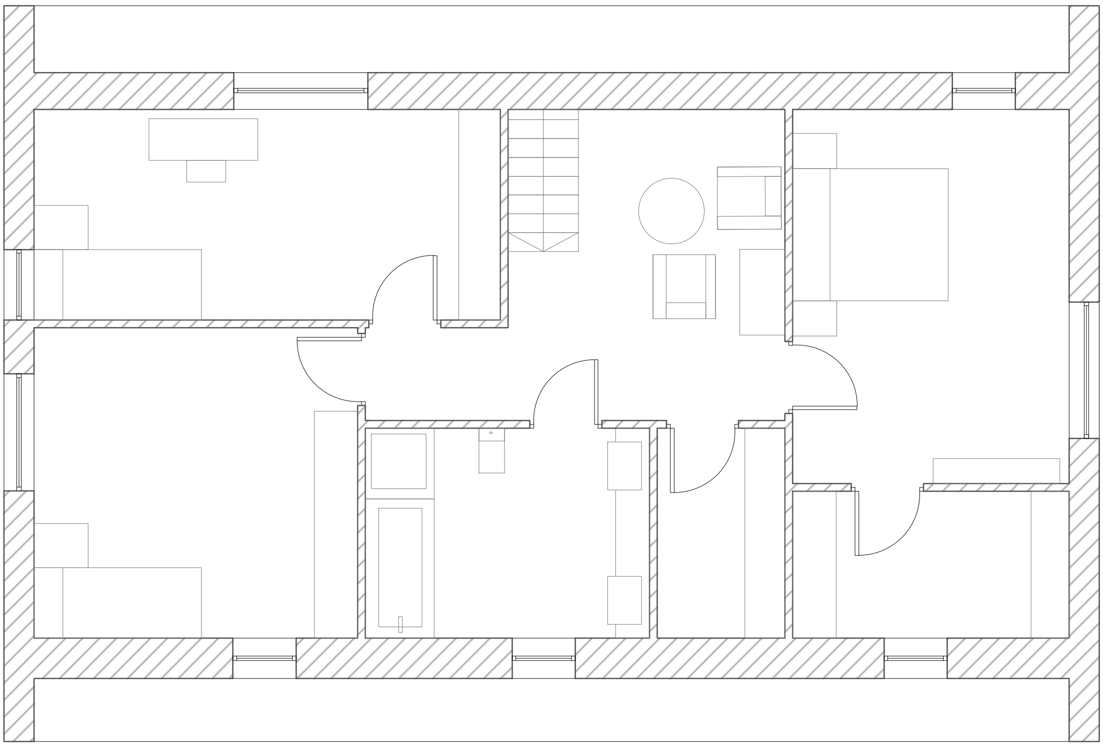
It is worth insisting on a correct initial design of the house, even at a significantly higher price, since as we have seen in our case, this investment is going to recover in the medium term and that in the long run we will get an important Saving on invoices.

The energy efficiency of homes and buildings should become more prominent when designing and building, as is well known, fossil fuels are a source of non-renewable energy, which according to many studies, in 2050 will have Been consumed due to the abusive use we make of it. That is why I believe that we must be more consistent both when designing and building buildings as in other areas where these fuels are used, such as the automotive or boiler design or industrial equipment.

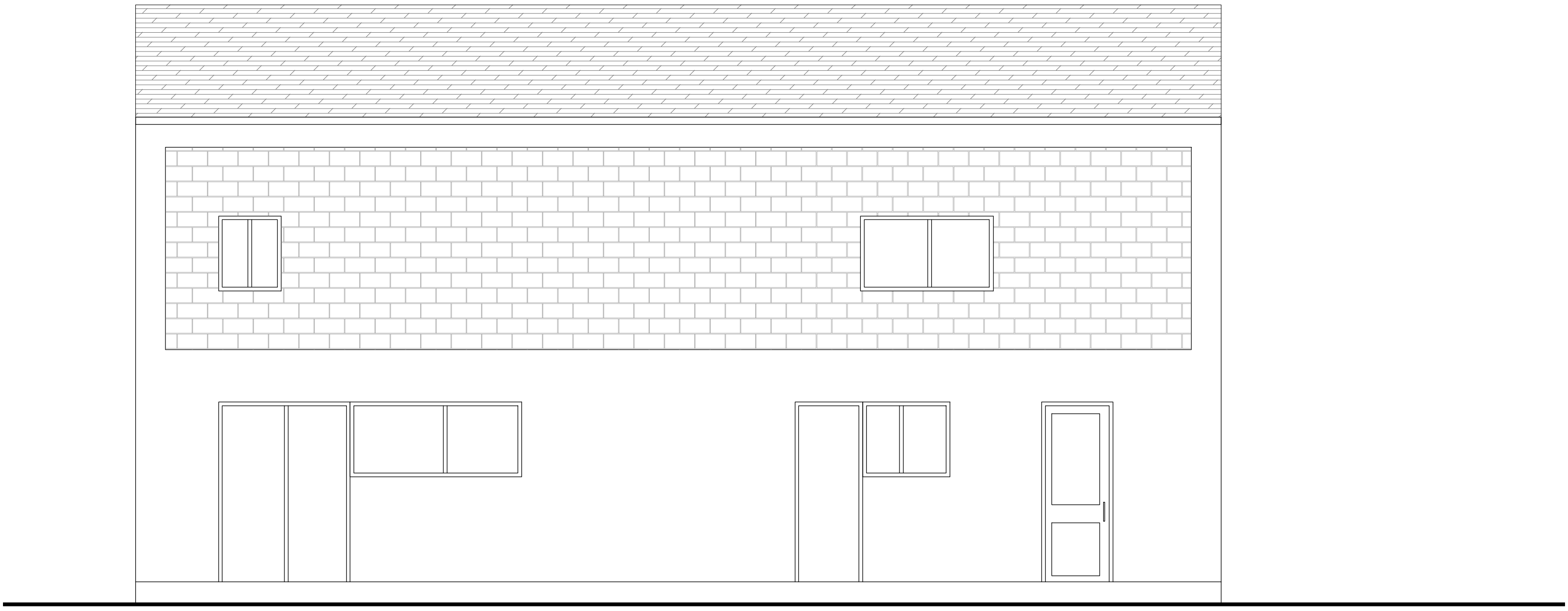
ANNEX 1: DWELLING PLANES



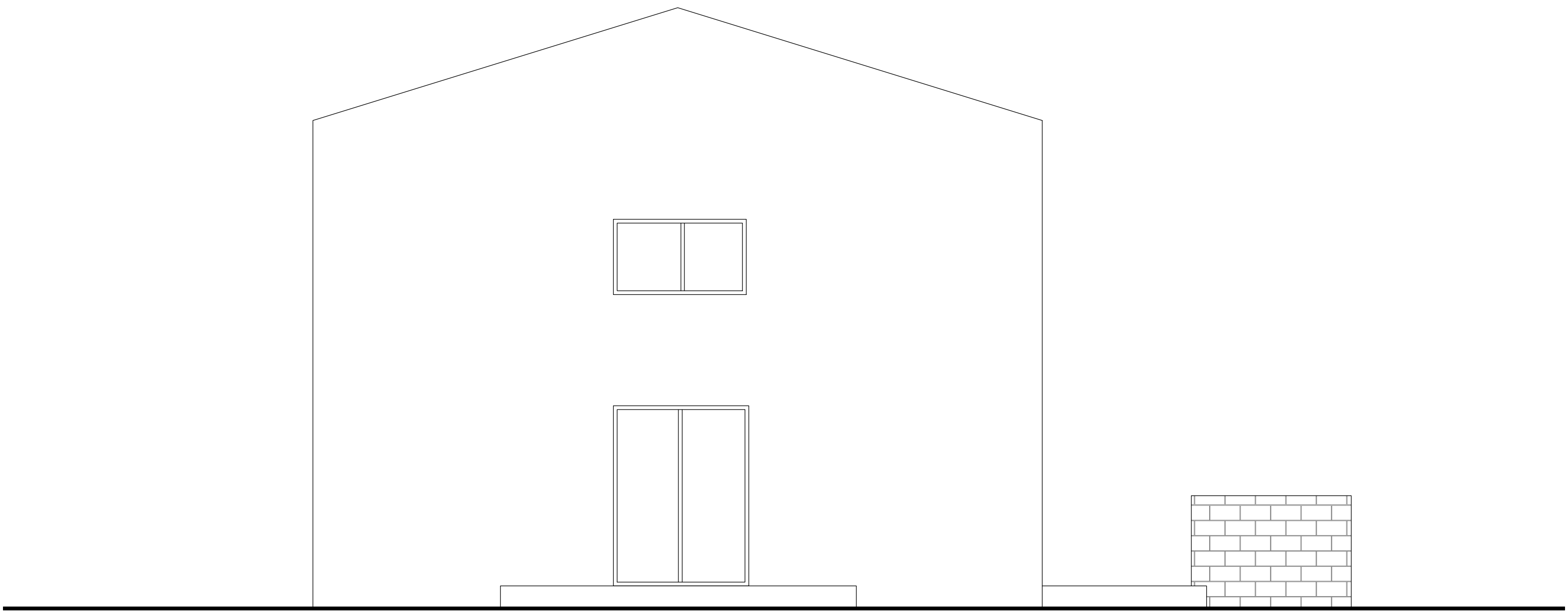
Main Elevation 1/100



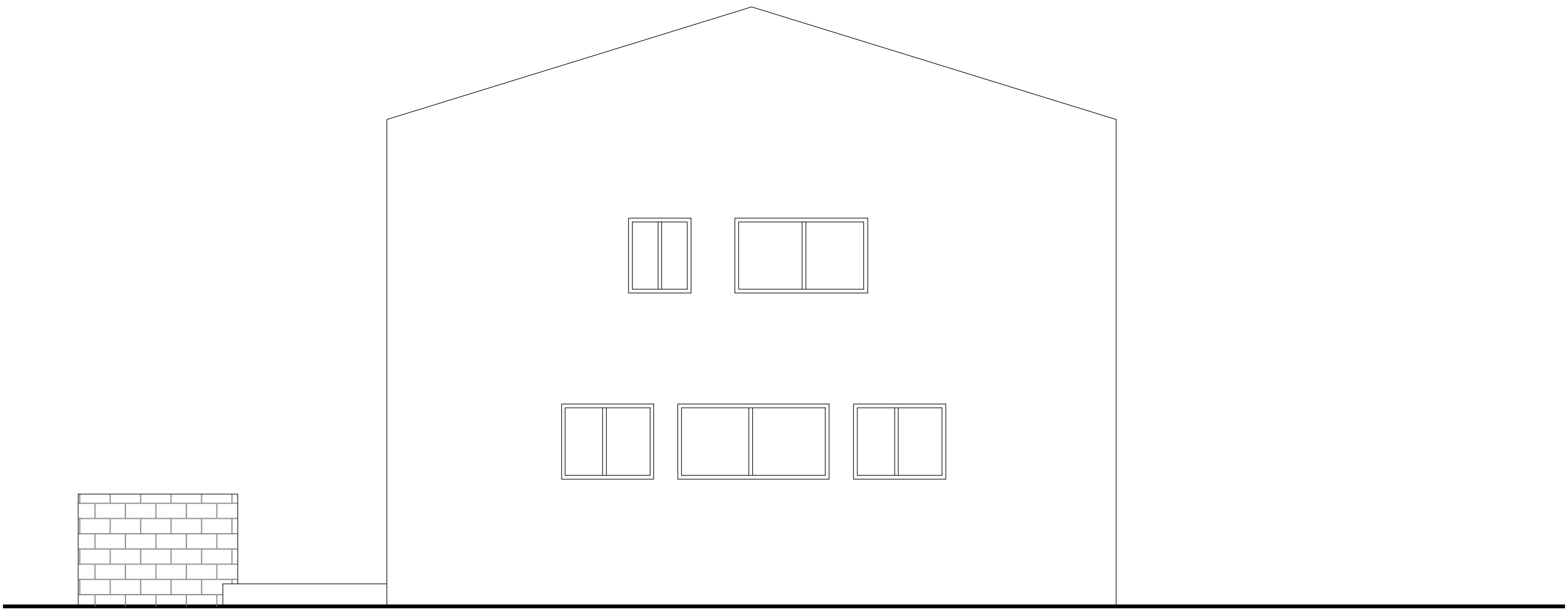
1 floor 1/100



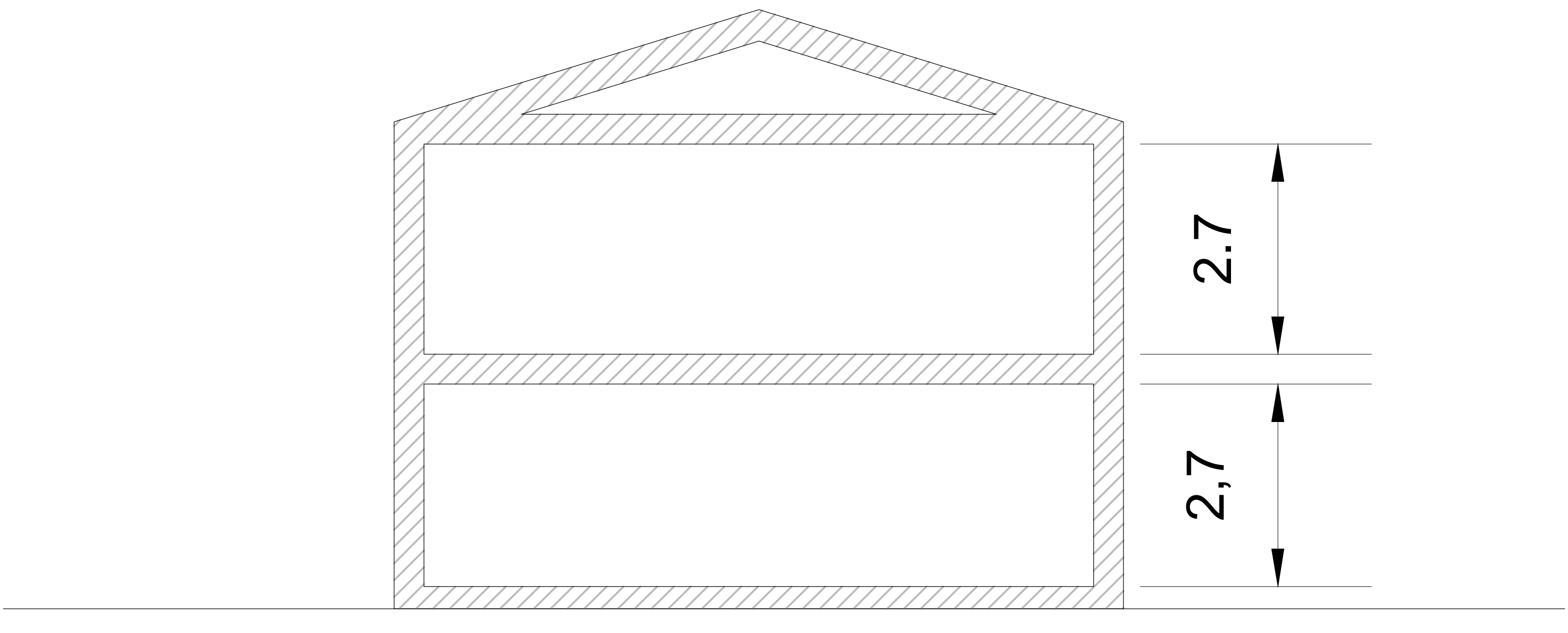
Back elevation 1/100



East Elevation 1/100



West elevation 1/100



Section 1/100