Cost Efficient Options and Financing Mechanisms for nearly Zero Energy Renovation of existing Buildings Stock

DELIVERABLE 2.1

REPORT PRESENTING THE 3 NZEB RENOVATION SCHEMES IN SPAIN FULLY DOCUMENTED WITH TECHNICAL AND ECONOMIC EVALUATION

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Deliverable D2.1: Short Description
The document presents three renovation schemes for Errenteria, Spain, with calculated energy performances and costs carried out through simulation software. The optimal renovation designed has been selected according overall energy efficiency, regulatory framework, comfort and visual impact of the solutions proposed
Keywords: Renovation schemes, historic buildings, nZEB

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Statement of originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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ABBREVIATIONS AND ACRONYMS

Acronym	Definition
AHU	Air Handled Unit
CCTV	Video Security Camera System
CHP	Combined Heat and Power
COP	Coefficient of Performance
CTE	Spanish Technical Code for construction
ESCO	Energy Service Company
EER	Energy Efficiency Ratios
HVAC	Heating Ventilation and Air Conditioning
ICT	Information and Communication Technology
nZEB	Nearly Zero Energy Building
PUR	Polyurethane
PV	Photovoltaic
RES	Renewable Energy Sources
VRV	Variable Refrigerant Volume
XPS	Extruded polystyrene

CERTUS PROJECT IN BRIEF

Southern European countries undergo a severe economic crisis. This hinders the compliance to the latest Energy Efficiency Directive, demanding strict energy efficiency measures for the public sector. Investments required to renovate public buildings and achieve nearly zero energy consumption have long payback times. So the interest of financing entities and ESCOs is small, especially when banks have limited resources. Many of the municipal buildings in Southern Europe require deep renovations to become nZEB and this should not be regarded as a threat but rather as an opportunity for the energy service and the financing sector.

The objective of the proposed action is to help stakeholders gain confidence in such investments and initiate the growth of this energy service sector.

Municipalities, energy service companies and financing entities in Italy, Greece, Spain and Portugal are involved in this project. The plan is to produce representative deep renovation projects that will act as models for replication. Twelve buildings, three in each of four municipalities one in each country have been selected. The partners will adapt existing energy service models and procedures and will work out financing schemes suitable for the 12 projects. Consequently, the partners will create materials, such as guides and maxi brochures, suitable to support an intensive communication plan.

The plan includes four workshops with B2B sessions targeted to municipalities, ESCOs and financing entities. These actions shall be complemented by four training activities targeting municipal employees and the participation in international events targeting all 3 groups of stakeholders. We expect that our action will have a significant impact by triggering investments in renovations to achieve nZEB and the uptake of the ESCO market in Southern European member states.

EXECUTIVE SUMMARY

This deliverable is part of the work carried out in Work Package 2 “Technical and Economic Validation of the nZEB Renovation Schemes” and describes the renovation schemes carried out for the three buildings of Errenteria Municipality, Spain.

Each renovation scheme, presented in this document, has been proposed according to the specific characteristics and conditions of the buildings considered within the project. These are:

- **Kapitain Etxea** building: located in the historic centre of the town with a typology characteristic of Errenteria and the Basque Country in general. It is currently used for administrative purposes, as part of the Municipal archive. It needs to be refurbished as it will host the Museum of the Basque Costume. The actual heating and ventilation system is not sufficient for the new use proposed and the occupation profile of the building, which will significantly increase. Also if the energetic performance of the building was calculated simulating the museum profile, the actual system will have to increase the heated and conditioned capacity, which is currently limited to some areas of the building. This circumstance leads to an increase of the energy demand compared to the current one. The installation of a new HVAC system, without the intervention on the envelope, will therefore lead to major energy consumption. Furthermore, the new use of the building requires for the adaptation of interior spaces and new comfort requirements, both for people and collections. For this reason, an integral rehabilitation process is needed, considering the preservation of the historic values, as well as the minimum reduction of useful spaces as main drivers.
- **City Hall**: impressive building created through the merger of three existing building. It is located at the heart of the city and is the administrative centre of the town. The entire complex was renovated in 2000, with the objective of achieving structural stability and guaranteeing the unitary use of a single building by the erection of a new structure behind the original façades of the two less significant buildings retaining their scale, materials and openings. The more significant original and historic City Hall was also renovated. The union of three building resulted in the presence of mezzanines and different levels in the same floor and in the integration of the existing courtyard as an atrium, covered by a skylight. Also if the envelope of the building was renovated in 2000 and has a reasonable energetic performance (insulated walls and almost all windows are double glazed), considering the high occupation profile by employees and the public in general, other energy efficient measures can be addressed. The renovation addressed in this project is mainly focused on the lighting system, the improvement of the heating system and the inclusion of PV panels, with the objective of achieving a nZEB.
- **Lekuona** building: it was a former bakery, erected in the 1970s and currently abandoned. It represents the industrial activity of the area, which was the main economic force of the town. The Municipality is carrying out an ambitious project to transform this abandoned building into a dance school and cultural centre. The Municipality has recently commissioned a renovation project in line with energy efficiency standards, which will qualify the building with the mark A, according to the requirements of the Technical Building Code of Spain (CTE). The initial idea was to address the whole rehabilitation in the framework of this project but, due to budgetary distribution, it was commissioned before the CERtuS project begun. In this case, the proposal addressed in this

document is therefore focusing on possible improvements in RES, proposing the inclusion of PV panels as an added value to the initial project.

The selected renovation options are the results of a critical reflection on the balance among energy efficiency, use profile, comfort and conservation. Different scenarios have been simulated in order to reach the optimum renovation design. The overall improvement of energy efficiency as well as use of renewable energy sources (RES) has been calculated with respect to the current buildings conditions. A first calculation on the economic investment needed to carry out the selected renovation option is also given.

1. KAPITAIN ETXEA

1.1. Building General Description

1.1.1. Location

The "*Kapitain Etxea*" building was erected in the 17th century and is owned by the Municipality of Errenteria, Basque Country, Spain.

FIGURE 1: KAPITAIN ETXEA – MAIN FAÇADE OF THE BUILDING (SOUTHWEST SIDE)

It is located in the historic centre of the town (*Erdialdea*) and it´s typology is characteristic of buildings throughout this part of Errenteria and the Basque Country. It is a three storey building made of thick stone ashlar walls with a horizontal timber post and beam structure and sloped timber roof. The following Figures describe the location, orientation and dimensions of the structure.

TABLE 1: LOCATION DATA OF THE BUILDING

Address	Kapitain Etxea, Kapitanenea Kalea 6, 20100 Errenteria, Gipuzkoa, Spain
Coordinates	43° 18' 46.32" N 1° 53' 55.19" W
Google Maps	https://www.google.es/maps/place/Kapitanenea+Kalea,+6,+20100+Errenteria,+Gipuzkoa/@43.3129143,-1.8986732,166m/data=!3m2!1e3!4b1!4m2!3m1!1s0xd51a8a793e9f7a9:0x8e38466103287fd

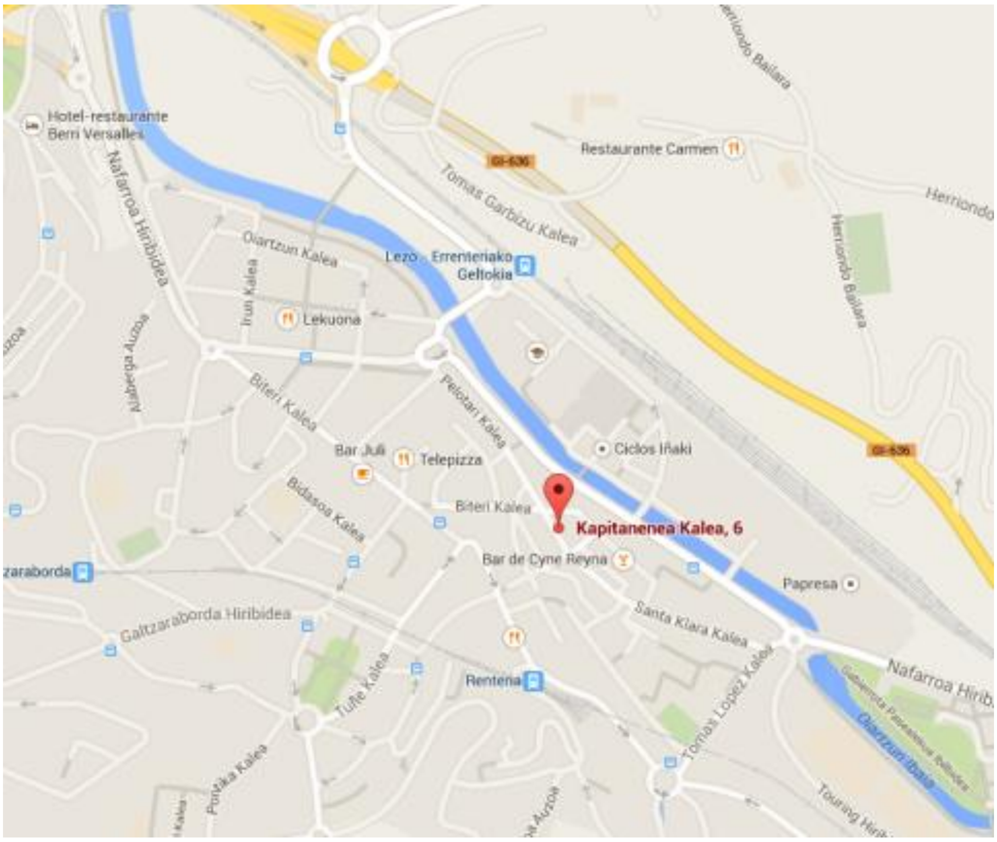


FIGURE 2: LOCATION IN THE CITY (MAP)

FIGURE 3: LOCATION IN THE CITY (AERIAL VIEW)

1.1.2. Shape and Orientation

The building has a rectangular form for the three existing floors in addition to an interfloor mezzanine loft under the roof. The overall dimensions are 7.90 m x 17.25 m. Kapitain Etxea was erected between party walls with two masonry façades (front and back) which correspond with the shorter sides of the floor area. The principal access is on Kapitanenea Kalea (street) while the back façade adjoins a small courtyard, which is included in the smallholding of the building.

Kapitain Etxea is very close (300 m) to the Municipal City Hall. They share the same gas-fired boiler that is used for the heating system of both buildings.

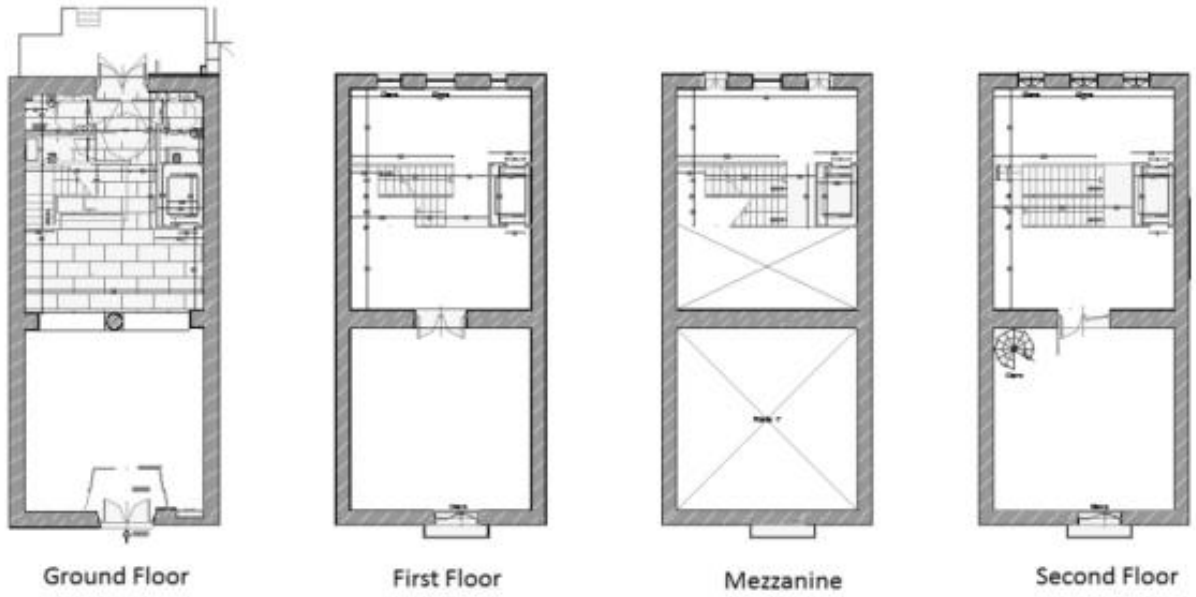


FIGURE 4: KAPITAIN ETXEA, PLANS OF EACH FLOOR

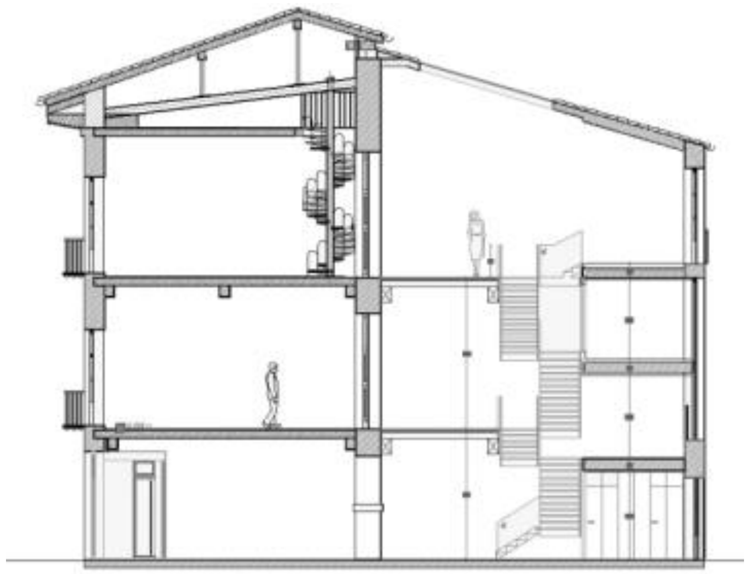


FIGURE 5: VERTICAL CROSS SECTION SHOWING THE THREE FLOORS PLUS NON-OCCUPIED LOFT

FIGURE 6: AERIAL VIEW

As can be seen in FIGURE 6 the building is oriented with an axis of 150º, with the main façade oriented to SouthWest and placed in the Kapitaenea Kalea (street).

1.1.3. Area and Volume

The building has total area of about 394.89 m^2 with a total used surface of about 341.20 m^2 (non-occupied loft is not considered) and a volume of 1,361.86 m^3.

Each floor has a surface of 109 m^2. They are divided in two parts by a load-bearing masonry wall perpendicular to the party walls (see FIGURE 4 and 5). Each room is rectangular-shaped and have a useful surface area of 47.90 m^2 and 57.30 m^2 (the smallest is the one adjacent to the main façade). Finally, the mezzanine surface is 20.10 m^2.

As can be seen in FIGURE 5, the roof is sloped and covered with tiles. It has a surface of 154.30 m^2 (19.25 m^2 corresponds to a skylight). The composition of the roof is complex; actually there are two separate roofs. This is explained in greater detail in Section 3.

1.1.4. Brief history

The first documented reference to the building is dated in the year 1696. However, it is supposed that the building was erected several years before and was once part of a larger building. On-site inspection of the main façades of Kapitain Etxea and the adjacent contiguous building confirms that both were once part of a single construction.

This continuous façade including alterations in the 19th century has hampered the study of the evolution of the building. In 1925 the original building was divided in two and nowadays it is possible to distinguish the differences only between the roofs.

In 1984 the Municipality of Errenteria refurbished Kapitain Etxea in order to transform the building into a cultural centre. Currently, the city is planning an intervention to replace the vertical core to install new stairs and an elevator.

1.1.5. Current and Future Use

The building is currently used for administrative activities and is part of the municipal archive and does not have a defined use profile because of difficult access and thus restricted to municipal employees. The Municipality has decided to house the Museum of the Basque Costume in Kapitain Etxea. Presently, the archive is being moved to another building and the municipal architects are designing the building which will accommodate this new use. One important aim is to retrofit the building according to nZEB standards with consideration for the new use: a museum open to the public from 10 am to 8 pm every day. The comfort conditions required for this activity will necessitate additional systems which will cause an inevitable increase of the energy demand (energy consumption is at a minimum given the current use of the building). Thus, it is necessary to wisely combine the use of technologies in order to reduce the energy consumption while increasing the use of Renewable Energy Sources (RES).

The following room distribution is planned for the building.

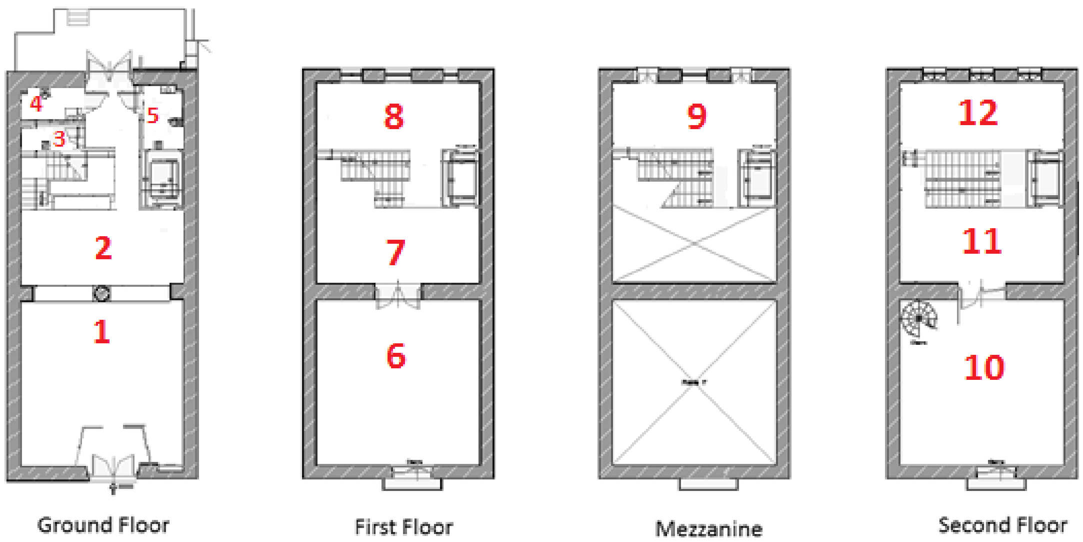


FIGURE 7: PLANNED ROOM DISTRIBUTION FOR KAPITAIN ETXEA

TABLE 2: ROOM USE FOR THE PLANNED DISTRIBUTION

Room	Floor	Use
1	G	Entrance
2	G	Reception
3	G	Storage room
4	G	Toilet
5	G	Toilet
6	1	1st floor main room
7	1	1st open space

Room	Floor	Use
8	1	2nd open space
9	M	3rd open space
10	2	2nd floor main room
11	2	4th open space
12	2	5th open space
13	UC	Loft

Room number 13 is placed under the roof. Use will be limited due to its complex access via a spiral staircase (see FIGURE 8).

The new function will require the installation of a new staircase to connect the floors. This decision is necessary due to the inadequacies of the existing stair.

A small project was planned by the municipal employees before the current project was conceived. Thus, all the plans used here show the new staircase.

FIGURE 8: SPIRAL STAIRCASE

1.2. CURRENT BUILDING CONDITIONS:

1.2.1. CONSTRUCTIVE BUILDING CHARACTERISTICS

Envelope Elements

Main façade

The wall of the main façade is constructive of sandstone ashlar masonry where the position of the horizontal structure can be easily understood because of a decorative gilded edge. The cornice at the top of the wall is also delineated by another ornamented edge. Each floor of the building have openings: the access door at the ground floor and two balconies at the upper floors (see FIGURE 9). The three openings are formed by a stone lintel and they are slightly offset from the vertical symmetry axis of the wall. Moreover, in the wall there is an ancient escutcheon (a shield-shaped emblem, displaying a coat of arms), probably carved in the 18th century. The wall has a thickness of 0.60 m and the intrados (interior surface) is covered by a layer of lime mortar and gypsum. This layer has a thickness of 0.05 m.

The total surface of the wall is 95.28 m^2, of which 8.48 m^2 are fenestrations (two balconies) and 5.70 m^2 for the main entrance door.

Rear façade

The rear façade, that adjoins a small courtyard, is also made of sandstone ashlar masonry, but in this case it is covered by a cement mortar and painted white (0.60 m + 0.05 m). It has nine openings: one door that allows the access to the courtyard, two small windows in the first floor, two balconies in the mezzanine and three balconies in the second floor. The remaining opening is a long window that goes from the first floor to the mezzanine (see FIGURE 9).

The total surface of the wall is 91.76 m^2, being 17.57 m^2 of fenestrations and 5.78 m^2 of the door that connects the building with the courtyard.

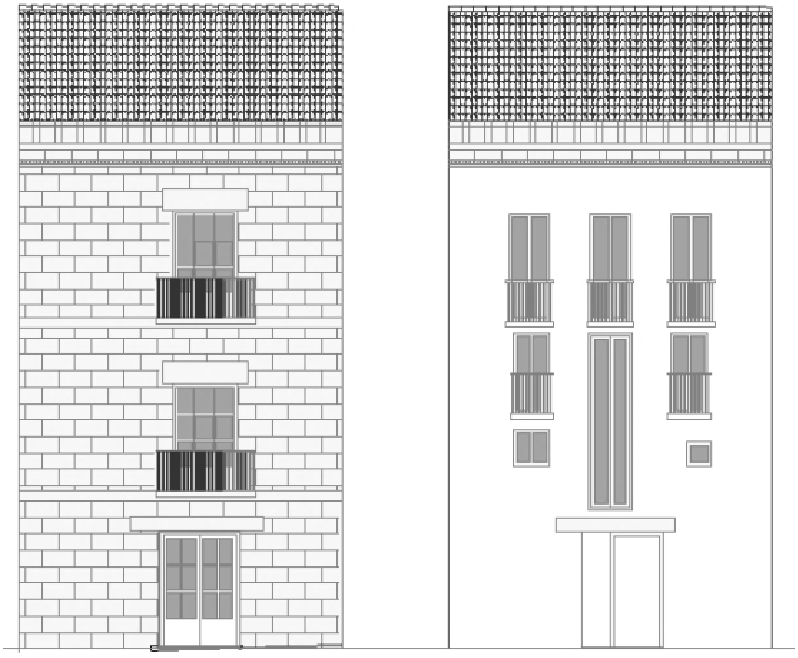


FIGURE 9: MAIN FACADE (LEFT) AND REAR FAÇADE (RIGHT)

Roof

As previously mentioned, the roof is clearly separated in two parts (FIGURE 10). The central partition corresponds to the inner load-bearing masonry wall. The part closest to the street contains a small attic space while the part facing the rear is open to below. The area facing the street is constructed in two parts with the gap between the two roofs at a height of 0.50 m. That small area is covered by small operable windows that are used for ventilation purposes. These windows and their details are shown in FIGURE 11.

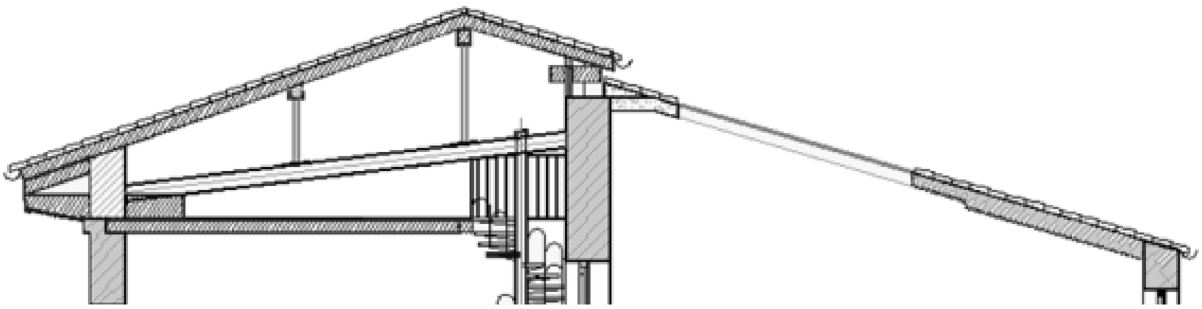


FIGURE 10: CROSS SECTION OF THE ROOF. THE MAIN FAÇADE IS ON THE LEFT

FIGURE 11: SMALL WINDOWS PLACED IN THE UNION OF BOTH ROOFS. GENERAL VIEW AND DETAILS

The two pitches roof is made of timber beams and ceramic tiles, between them there is a waterproofing layer. There is no thermal insulation in this part of the envelope. The space between the beams contains gypsum and other filling materials (FIGURE 12) which create a traditional and attractive finish. There is a small skylight that cannot be opened. The second part, facing the rear courtyard, presents the same constructive typology however, the inner finish is different; and the wood girders are hidden by a regular gypsum finish.

FIGURE 12: CONSTRUCTIVE TYPOLOGY OF THE TWO WATERS ROOF

The roof was not rehabilitated in 1984. However, a new skylight was open in the existing roof, which is the reason for the different inner finishes.

FIGURE 13: GENERAL VIEW OF THE SKYLIGHT AND DETAIL

The state of conservation of the roof is not satisfactory. Water infiltration has been detected during the visual inspection. These pathologies are related to the poor conservation of the exterior roof. Both roofs have gutters in the three existing eaves with downspouts releasing the water into the street and courtyard.

The total surface of the roof is 146.80 m^2, being 22.20 m^2 of fenestrations (small windows and skylights).

Windows

All windows are single glazing with wood frames. Due to the age of these elements, small air infiltrations are expected, affecting the air tightness of the building. The two doors are made of thick wood. The frame of the skylight is made of aluminium.

Main façade

In the front there are two openings:

- 1 operable door with 2.85 x 2.00 m
- 2 operable balconies with 2.65 x 1.60 m

FIGURE 14: MAIN FAÇADE. GENERAL VIEW OF THE BALCONY OF THE 1ST FLOOR AND DETAIL OF ITS FENESTRATION

Rear façade

In the back there are the following windows/doors:

- 1 operable door with 2.85 x 2.00 m
- 1 operable window with 0.60 x 0.60 m
- 1 operable window with 0.90 x 0.90 m
- 2 operable balconies with 2.00 x 0.90 m
- 3 operable balconies with 2.65 x 1.00 m
- 1 fixed long window with 4.41 x 1.10 m

FIGURE 15: REAR FAÇADE. GENERAL VIEW OF ONE BALCONY OF THE MEZZANINE AND DETAIL OF ITS FENESTRATION

Roof

In the roof there are the following openings:

- 1 fixed skylight with 5.05 x 3.85 m
- 1 small fixed skylight in the two waters roof with 0.50 x 0.50 m
- 7 operable small windows with 0.35 x0.50 m

All windows and balconies of the walls have curtains. According to the conservation plan, fenestrations (openings) do not have any historic value, and can be replaced. There are no external shading devices in any windows, doors or skylights. Important shading is ensured by the urban environment through the adjacent buildings (narrow streets).

Airflows and Pathologies

The building does not present major airflows. Doors, usually a critical point for air infiltration, fit snugly in their frames and the frames are installed tightly against the masonry. Despite being old, windows and balconies are well preserved.

As mentioned earlier, water is infiltrating through the roof especially under the attic space.

This is caused by the poor state of conservation of the roof. The analysis of these areas is outside the scope of this study. Nevertheless, the effects of the water infiltration can be easily observed. The constituent materials of the roof, such as wood beams and the infill present significant deterioration. Additionally, the structure of the roof is reinforced with steel beams that reduce the functionality of the loft.

FIGURE 16: CONSERVATION STATE OF THE ROOF

FIGURE 17: TWO DETAILS OF THE ADDITIONAL STEEL STRUCTURE THAT BEARS THE ORIGINAL WOOD STRUCTURE OF THE ROOF

1.2.2. Energy Systems

Lighting

Most of the luminaries are placed or hanged below the timber beams (FIGURE 18). The majority of the lighting is with individual fluorescent bulbs and tubes. The distribution of the luminaries along the different floors does not follow a uniform pattern. However, in general individual bulbs are placed in parallel to the party walls while the luminaries for the tubes are located perpendicularly. Halogen lamps are also used with some of them are placed in a false ceiling located in the ground floor and others are located in walls. Due to the limited use of the building as the municipal archive, some luminaries are without bulbs or tubes.

FIGURE 18: TWO EXAMPLES OF LUMINARIES INSTALLED BELOW THE SLAB IN THE GROUND FLOOR

During the visual inspection 5 different types of lighting fixtures have been identified:

- *Type A:* Compact fluorescent light bulb of 30 W. This light type is the most common in the building, located mainly in the rooms that are adjacent to the main façade. They are installed in a very haphazard way, as can be observed in FIGURE 18.
- *Type B:* Fluorescent T8 lamp of 58 W with magnetic ballast, condenser and compensation. They are integrated in luminaries with reflectors. Luminaries present one or two lamps.
- *Type C:* Fluorescent T8 lamp of 36 W with magnetic ballast, condenser and compensation. They are integrated in luminaries with reflectors. Luminaries present one or two lamps.
- *Type D:* Halogen lamp of 75 W. They are located in the ground level, integrated in a false ceiling that is particular of the rear of the ground floor.
- *Type E:* Halogen lamp of 100 W. The luminaries that have this type of lamp are placed on walls.

The number and the installed power of each type of lamp at each level of the building are presented in TABLE 3.

TABLE 3: TYPES AND QUANTITIES OF LAMPS

Floor	Type of light	Power (W)	Number	Total Power (W)	Total installed lighting power per floor (W)
Ground	A	30	31	930	2344
	B	58	8	464	
	D	75	10	750	
	E	100	2	200	
First	A	30	19	570	1282
	B	58	4	232	
	C	36	5	180	
	E	100	3	300	
Mezzanine	A	30	3	90	162
	C	36	2	72	
Second	A	30	29	870	986
	B	58	2	116	
Loft	C	36	6	216	216
			TOTAL	126	4990

There is no automatic control for lighting. All the studied luminaries are locally controlled by conveniently distributed switches. Due to the characteristics of the building (stone walls and visible timber slabs) the electric system is exposed.

FIGURE 19: ELECTRIC SYSTEM EXPOSED, MAIN FAÇADE

HVAC

VENTILATION SYSTEM

There is forced air ventilation in the main room of the second floor (the one closest to the main street Kapitanenea Kalea). The rest of the building does not have any climate control or forced ventilation. The total ventilated area is 48 m^2, with a volume of 188 m^3.

This forced ventilation is carried out by means of double aspiration electric centrifugal fans. It is complemented with a heat recovery device that extracts heat from the heating system in order to warm the air that is being moved (see FIGURE 20). The total power of the fan is 6.5 kW. At the moment of the visit the fan was working.

FIGURE 20: ELECTRIC FAN PLACED IN THE MAIN ROOM OF SECOND FLOOR

HEATING SYSTEM

The heating system is designed to heat all the rooms of the building. The system if formed by 2 string system heat radiators that are warmed by hot water.

The supply system is a natural gas-fired boiler placed in the City Hall, another municipal building placed at 350 m. This boiler produces hot water depending on the needs of the City Hall and Kapitain Etxea. It is a model of the brand Roca and it has a COP of 0.88 and total installed power of 232.60 kW.

The hot water is distributed to the building by underground uninsulated pipes buried in the street. Once the pipes are inside the building, the net is ramified in collectors to reach the different heat radiators.

FIGURE 21: TWO IMAGES OF HEAT RADIATORS

Heat radiators are made of cast iron (FIGURE 21). All the heaters have three columns and a height of 1.20 m.

The boiler, placed in the City Hall, is controlled by an outdoor temperature sensor. This system is not very effective in terms of energy efficiency. The main control for the building under study depends on conditions in another building. Inside Kapitain Etxea, all the radiators are manually managed by valves that control the flow of hot water.

ICT

Currently there are no computers or printers in the building due to its use.

Others

The building has a security system that works electrically.

1.2.3. ENERGY CONSUMPTION & ENERGY GENERATION

Electricity

The building receives electricity in single-phase voltage of 230 V (Low Voltage). Then, the contracted power is 13.20 kW. The characteristics of the contract are presented in TABLE 4.

TABLE 4: CHARACTERISTICS OF THE ELECTRICITY CONTRACT

Electricity contract	
Voltage Level	Low Voltage (230V)
Contracted Power	13.20 kW
Tariff Option	Medium utilizations
Cycle	Diary

In 2013 the building had an electricity consumption of 4,916 kWh and an associated annual cost of about 760 €. This is caused by the current use profile of the building. It is only used for sporadic or punctual enquiries, so there is not a regular pattern for electricity consumption.

Gas

As described above, the heating system of Kapitain Etxea is supplied by a gas-fired boiler that is placed in the City Hall, located nearby. The hot water is driven to the building through underground pipes below Kapitanenea Kalea.

Currently, the Municipality has no data concerning the total consumption of the boiler. Thus, it is not possible to obtain accurate data about the gas consumption for Kapitain Etxea. In TABLE 5 the gas consumption from December 2012 to November 2013 is shown.

Nevertheless, as there is no continuous use of the building therefore the gas consumption in Kapitain Etxea is almost zero.

TABLE 5: GAS CONSUMPTION IN THE PERIOD DECEMBER 2011-NOVEMBER 2012

Year	Month	Thermal Energy [kWh]	CO_2 Emissions [$kgCO_2$]
2012	December	14,590	2,941
2013	January	29,260	5,889
	February	41,251	8,316
	March	23,349	4,707
	April	18,671	3,764
	May	6,039	1,217
	June	0	0
	July	0	0
	August	0	0
	September	0	0
	October	38	8
	November	12,800	2,580
	TOTAL	131,408	26,492

The average cost of gas was 0.05 €/kWh. So the energy running costs of the gas-fired boiler for the whole year was 7,227€.

RENEWABLE ENERGY SOURCE (RES)

Currently, the building does not have any renewable generation source. The Hot Water necessary for the heating system and domestic use is produced in the City Hall.

Final energy consumption and CO_2 emissions

Kapitain Etxea is a small building that is currently being used for storage purposes. Hence, its use does not follow any regular pattern. However, the Errenteria Municipality has decided to renovate this building in order to establish a museum. The idea is to define a new building with an optimum energy performance, in line with the targets of CERtuS project.

In order to achieve this, most of the building will be renovated. First, the energy demand will be reduced by improving the envelope of Kapitain Etxea (opaque envelope and openings). Secondly, the building environmental and lighting systems will be replaced with more efficient models. The current systems are obsolete and their adaptation would be ineffective. Finally, the use of renewable energy sources will be considered. Nevertheless, due to the historic value of the building, its location in a historic district and its limited space, this last step must be considered carefully.

In TABLE 6 the annual forecast energy consumption of the building is displayed.

TABLE 6: ANNUAL ENERGY CONSUMPTION OF KAPITAIN ETXEA

	Final Energy kWh	Energy Dens. kWh/m2	Primary Energy kWh	CO_2 Emissions kg CO_2
Total	4,916	14.41	12,830.76	3,190.5

1.3. RENOVATION SCHEME

1.3.1. Aim of the renovation plan

As Kapitain Etxea is a building that has not suffered any extensive renovations related to energy efficiency, it is therefore convenient to start the renovation plan with an energy demand analysis. Development of simulation models requires multiple parameters to model reality. A geometrical model is generated with DESIGNBUILDER software for Kapitain Etxea according to real dimensions, typologies of the constructive elements and properties that are assigned to its materials and HVAC systems. In FIGURE 22 it is possible to observe a general view of the model; the building is represented in grey colour.

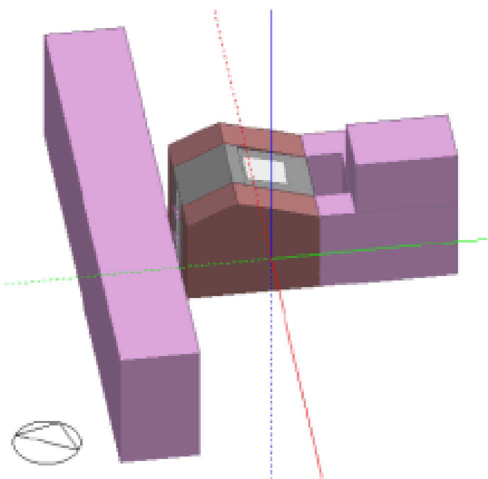


FIGURE 22: KAPITAIN ETXEA MODEL IN DESIGNBUILDER

As the building use is going to be changed, simulations have been done considering Kapitain Etxea as a museum. This means that the building use parameters such as occupation density and profile, the amount of air that needs to be changed, temperature setpoints, average illuminance, installed power for the lighting system, etc. have all been considered according to a museum use. In TABLE 7 most of those parameters are represented.

TABLE 7: BUILDING USE MAIN PARAMETERS

Common areas (GP, P1 + M, P2)			
Density of occupation		0.15 person/m^2	
Occupation profile		Timetable	Number of users
		08:00 – 10:00	12
		10:00 – 12:00	25
		12:00 – 14:00	50
		14:00 – 17:00	37
		17:00 – 18:00	50
		18:00 – 19:00	25
		19:00 – 21:00	12
		21:00 – 07:00	0
Ventilation rate		IDA 2: 12,5l/s p	
Heating system	Temperature setpoint	22ºC	
Cooling system	Temperature setpoint	26ºC	
Average illuminance at the working plane (E_m)		300lux	
Average installed lighting power		5 W/(m^2·100lux)	
Timetable (occupation, lighting, HVAC systems)		All the year	

In order to establish the best renovation scheme, initially, two scenarios have been considered: the first one is based on the minimum requirements stated by the CTE 2013 (the Spanish Technical Code for Construction) and the second one is an improved scenario. The results have been shared with the municipal technicians in order to decide which proposal will finally be carried out. However, in order to minimize the reduction of interior space (for wall insulation or the creation of a false floor to isolate the ground floor) a third proposal has been developed.

1.3.2. ENERGY DEMAND REDUCTION

One of the outputs of the conducted energy demand assessment is the energy transmission through the envelope of the building. The analysis of this information show which are the “weak” elements that must be renovated in order to reduce these undesirable energy flows. In the case of Kapitain Etxea, walls and windows are the main points that should be studied, as it can be seen in FIGURE 23.

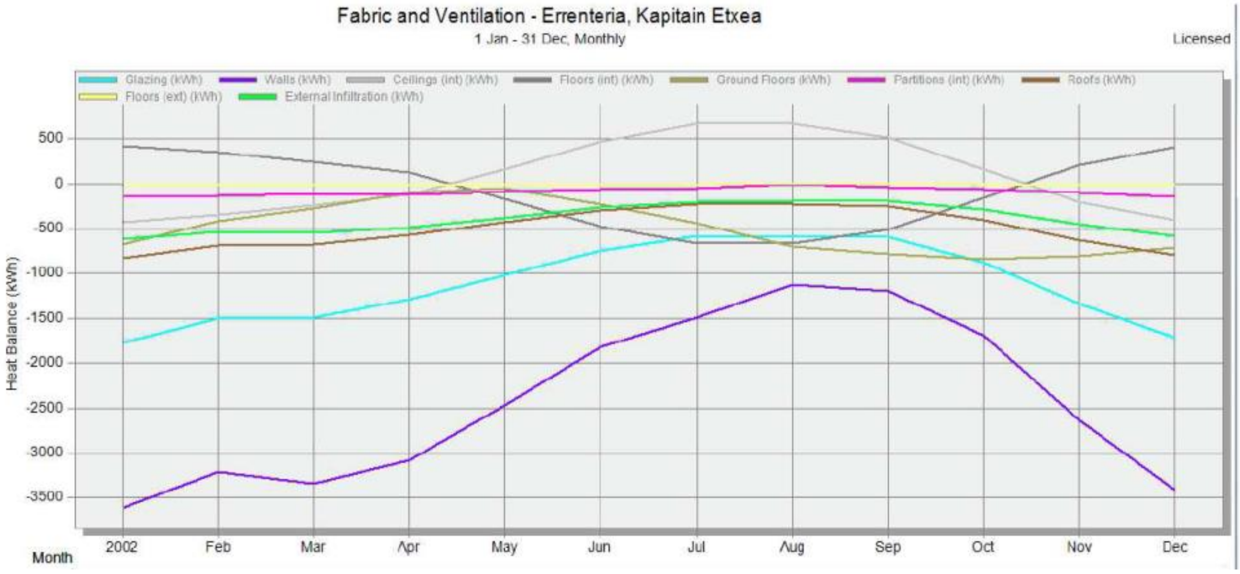


FIGURE 23: ENERGY FLOWS THROUGH THE DIFFERENT CONSTRUCTIVE ELEMENTS OF KAPITAIN ETXEA. CURRENT STATE

Additionally, the roof and the ground floor have an important impact in the existence of thermal loses through the building envelope. Thus, the first step that needs to be undertaken, in order to reduce the energy demand of the building, is to improve the thermal performance of the different components and materials of the envelope.

Opaque envelope

WALLS

There are two walls where intervention is possible: the main wall that adjoins Kapitanenea Street and the back wall that is facing the courtyard. Both walls have the same typology; they are formed by thick blocks of sandstone, with the difference of a thin layer of render that covers the back wall. As the outermost surface of the front wall is listed due the historic value of the building, the intervention must be done on the inner surface. The idea is to improve the U-value of both walls by adding insulating materials.

Three new typologies are proposed for these walls: the first proposal aims to fulfil the requirements stated by the CTE 2013, the Spanish standard for construction; the second is based on the experience of the partners involved in the project and the third is based on the Municipality criteria, whose aim is to minimise interior space reduction. In the following table the current state and the three proposals are included.

TABLE 8: WALLS TYPOLOGIES

Wall type	Typology	Characteristics
Current	*Outer surface* - 600mm sandstone - 20mm mortar render *Inner surface*	U-Value surface to surface: 4.67 W/m^{2}K R-Value: 0.38 m^{2}K/W U-Value: 2.60 W/m^{2}K
Proposal 1 – CTE 2013	*Outer surface* - 600mm sandstone - 35mm mineral wool - 20mm mortar render *Inner surface*	U-Value surface to surface: 0.74 W/m^{2}K R-Value: 1.51 m^{2}K/W U-Value: 0.66 W/m^{2}K

Proposal 2 – Own experience	*Outer surface* - 600mm sandstone - 120mm mineral wool - 20mm mortar render *Inner surface*	U-Value surface to surface: 0.24 W/m^{2}K R-Value: 4.25 m^{2}K/W U-Value: 0.23 W/m^{2}K
Proposal 3- Municipality	*Outer surface* - 600mm sandstone - 70mm mineral wool - 50mm mortar render *Inner surface*	U-Value surface to surface: 0.38 W/m^{2}K R-Value: 2.83 m^{2}K/W U-Value: 0.35 W/m^{2}K

ROOF

The roof structure is made of timber and is in a poor condition. For this reason, its conservation has been rejected and a new timber roof will be installed. This provides the opportunity to improve the thermal performance of this important element. The construction will be similar, but the insulation and waterproof materials will be improved. The current state and the three proposals are described in TABLE 9.

TABLE 9: ROOF TYPOLOGIES

Roof type	Typology	Characteristics
Current	*Outer surface* - 25mm ceramic tile - 20mm timber purlin - 20mm timber flooring *Inner surface*	U-Value surface to surface: 3.66 W/m^{2}K R-Value: 0.41 m^{2}K/W U-Value: 2.42 W/m^{2}K
Proposal 1 – CTE 2013	*Outer surface* - 25mm ceramic tile - 10mm timber purlin - 1mm breathable sheet - 60mm PUR - 1mm vapour barrier - 20mm timber flooring *Inner surface*	U-Value surface to surface: 0,40 W/m^{2}K R-Value: 2.65 m^{2}K/W U-Value: 0.38 W/m^{2}K
Proposal 2 – Own experience	*Outer surface* - 25mm ceramic tile - 10mm timber purlin - 1mm breathable sheet - 100mm PUR - 1mm vapour barrier - 20mm timber flooring *Inner surface*	U-Value surface to surface: 0.25 W/m^{2}K R-Value: 4.19 m^{2}K/W U-Value: 0.24 W/m^{2}K
Proposal 3 - Municipality	*Outer surface* - 25mm ceramic tile - 10mm timber purlin - 1mm breathable sheet - 100mm PUR - 1mm vapour barrier - 20mm timber flooring *Inner surface*	U-Value surface to surface: 0.25 W/m^{2}K R-Value: 4.19 m^{2}K/W U-Value: 0.24 W/m^{2}K

SLAB ON GROUND

Current slab on ground, which is in direct contact with the soil, is formed by 200 mm of cast concrete. This construction system is greatly affected by the presence of a high ground water table. The presence of moisture has been detected in the floor and at the base of the walls. Again three proposals have been considered.

TABLE 10: GROUND FLOOR PAVING TYPOLOGIES

Paving type	Typology	Characteristics
Current	*Outer surface* - 200mm cast concrete *Inner surface*	U-Value surface to surface: 7.00 W/m²K R-Value: 0.41 m²K/W U-Value: 2.42 W/m²K
Proposal 1 – CTE 2013	*Outer surface* - 70mm concrete - 5mm PUR - 70mm concrete - 150mm air gap - 50mm concrete - 200mm gravel *Inner surface*	U-Value surface to surface: 0.54 W/m²K R-Value: 2.12 m²K/W U-Value: 0.47 W/m²K
Proposal 2 – Own experience	*Outer surface* - 70mm concrete - 100mm PUR - 70mm concrete - 150mm air gap - 50mm concrete - 200mm gravel *Inner surface*	U-Value surface to surface: 0.18 W/m²K R-Value: 5.78 m²K/W U-Value: 0.17 W/m²K
Proposal 3 - Municipality	*Outer surface* - 70mm concrete - 70mm PUR - 70mm concrete - 150mm air gap - 50mm concrete - 200mm gravel *Inner surface*	U-Value surface to surface: 0.23 W/m²K R-Value: 4.62 m²K/W U-Value: 0.22 W/m²K

Openings

The current windows and balconies are formed by single pane windows with wood frames. These fenestrations do not have historic value and can be replaced. This will greatly improve the thermal performance of the envelope. Again, three proposals have been developed and are shown in TABLE 11.

TABLE 11: WINDOW AND BALCONIES TYPOLOGIES

Window type	Typology	Characteristics
Current	4, single	Total solar transmission (SHGC): 0.82 Light transmission 0.88 U-Value (ISO 15099/NFRC): 5.78 W/m²K
Proposal 1 – CTE 2013	4-12-4, air filled	Total solar transmission (SHGC): 0.74 Light transmission 0.80 U-Value (ISO 15099/NFRC): 2.72 W/m²K
Proposal 2 – Own experience	6-13-6, low-e, argon filled	Total solar transmission (SHGC): 0.57 Light transmission 0.74 U-Value (ISO 15099/NFRC): 1.49 W/m²K
Proposal 3 - Municipality	4-16-4, low-e coated, air filled	Total solar transmission (SHGC): 0.63 Direct solar transmission: 0.51 Light transmission 0.76 U-Value (ISO 15099/NFRC): 1.92 W/m²K

The same process is being done with the skylight. For the current state the same glazing is considered for the skylight, due to the difficulties to confirm the exact typology of this opening.

TABLE 12: SKYLIGHT TYPOLOGIES

Skylight type	Typology	Characteristics
Current	4, single	Total solar transmission (SHGC): 0.60 Light transmission 0.43 U-Value (ISO 15099/NFRC): 5.78 W/m²K
Proposal 1 – CTE 2013	4-6-4, air filled	Total solar transmission (SHGC): 0.36 Light transmission 0.56 U-Value (ISO 15099/NFRC): 3.29 W/m²K
Proposal 2 – Own experience	6-6-6, low-e, air filled	Total solar transmission (SHGC): 0.57 Light transmission 0.75 U-Value (ISO 15099/NFRC): 2.43 W/m²K
Proposal 3- Municipality	No skylight	Removal of the skylight and inclusion of PV panels

Summarizing these are the actions proposed to reduce the energy demand of Kapitain Etxea by altering the typology of the building envelope. By means of the simulations done in EnergyPlus, it is possible to assess the reduction of the heating demands of this case study. Firstly, as shown in FIGURE 23, the current energy flows through the envelope are analysed. Secondly, improvements are made by the inclusion of different renovation scenarios. It can be observed how these flows are being progressively reduced by FIGURE 24, FIGURE 25 and FIGURE 26.

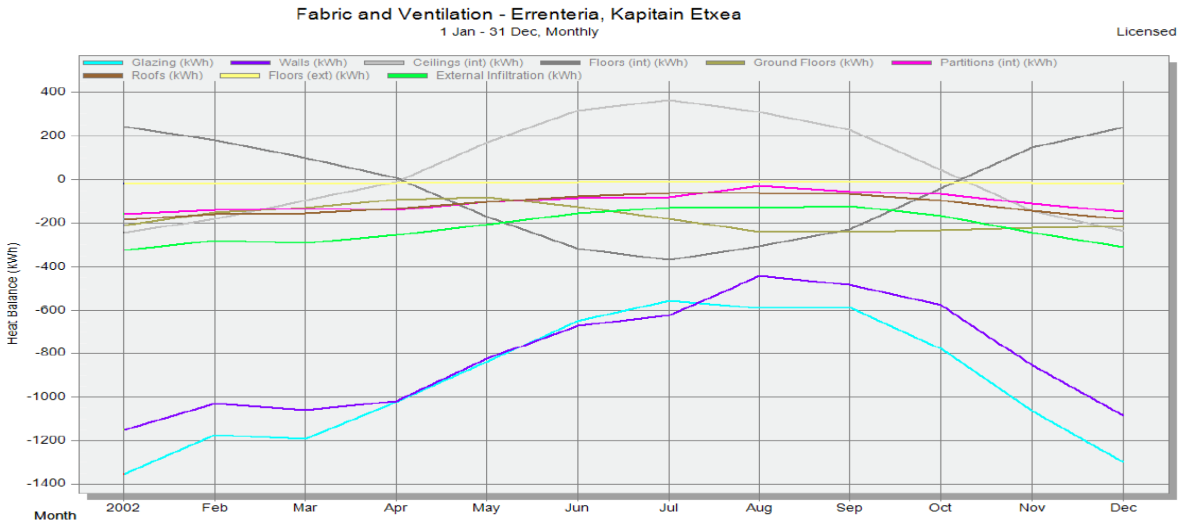


FIGURE 24: ENERGY FLOWS THROUGH THE DIFFERENT CONSTRUCTIVE ELEMENTS OF KAPITAIN ETXEA. PROPOSAL 1

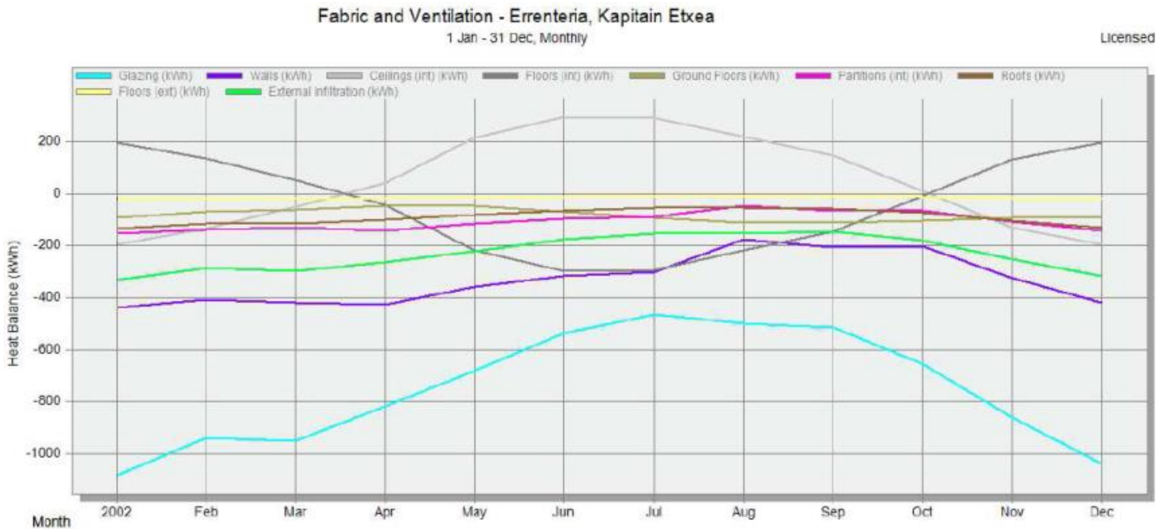


FIGURE 25: ENERGY FLOWS THROUGH THE DIFFERENT CONSTRUCTIVE ELEMENTS OF KAPITAIN ETXEA. PROPOSAL 2

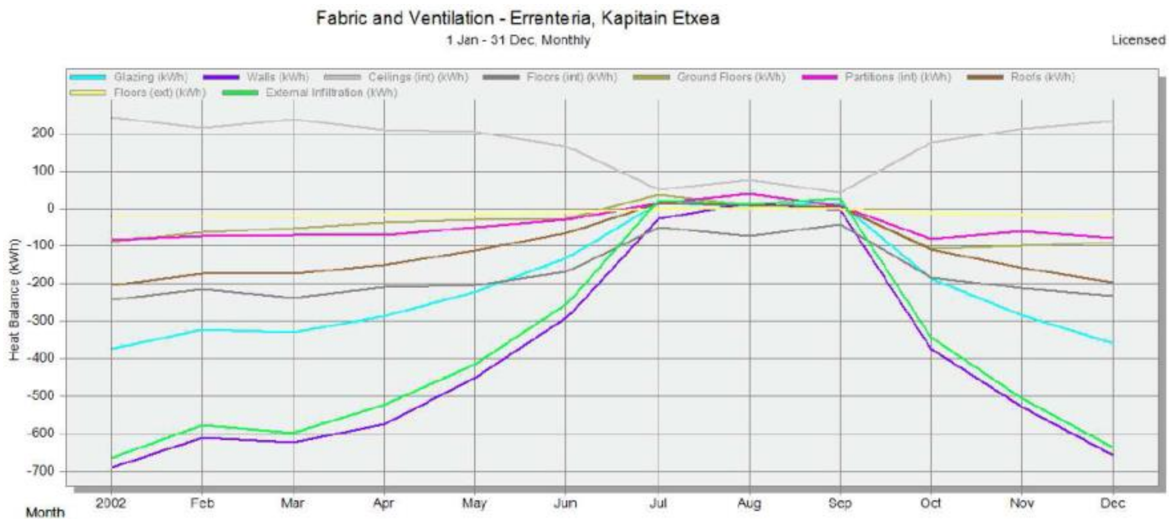


FIGURE 26: ENERGY FLOWS THROUGH THE DIFFERENT CONSTRUCTIVE ELEMENTS OF KAPITAIN ETXEA. PROPOSAL 3

In order to evaluate the energy demand variations for the different scenarios, a HVAC system with an ideal value of Coefficient of Performance (COP) of 1 has been modelled This system does not include heat recovery for ventilation.

The annual energy demand values are summarised in TABLE 13TABLE 13: ENERGY DEMAND IN KAPITAIN ETXEA and Figure 27:

TABLE 13: ENERGY DEMAND IN KAPITAIN ETXEA

System	Current [kWh]	Proposal 1 – CTE [kWh]	Proposal 2 [kWh]	Proposal 3 [kWh]
Heating	54,383.1	23,282.3	14,774.9	17,181.6
Cooling	642.4	511.8	1,245.5	1,302.8

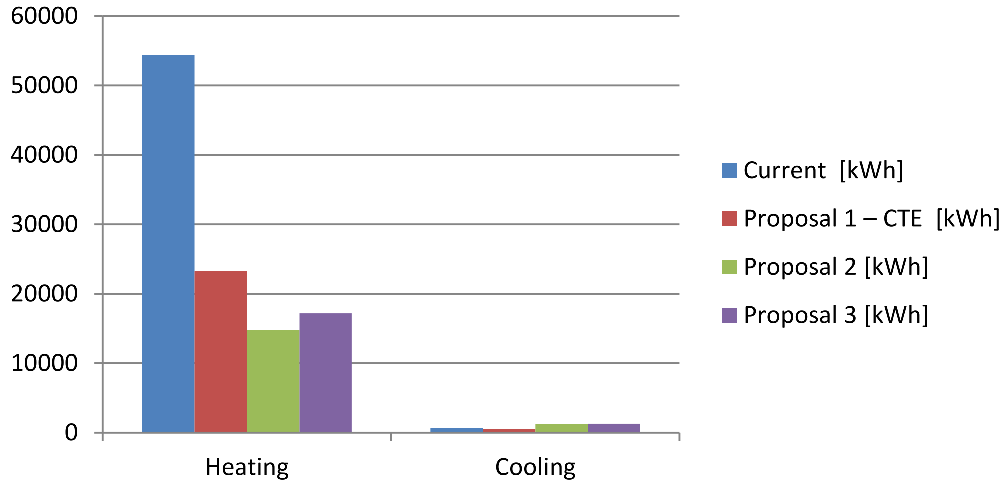


FIGURE 27: ENERGY DEMAND IN KAPITAIN ETXEA

It is possible to see how there is an evident decrease in the energy demand for the heating system. On the other hand, the cooling demand is slightly increased. Nevertheless, this building does not have considerable cooling loads given its geographic location. In summary, the first proposal represents an energy demand reduction of 57% while the second proposal entails a reduction of 73% and the third one a 68%. It is necessary to highlight that this assessment has been made considering the proposed use as a museum. It is not possible to compare with the current use because it is very irregular, so it is difficult to define properly.

1.3.3. Energy Systems

Current systems, mainly lighting and Heating, Ventilation and Air Conditioning (HVAC) will be completely renovated. In the case of the lighting system, the current installation cannot be adapted for the new use, as it is very irregular and obsolete for the future requirements of a museum. The new lighting system will be designed to fulfil the demanded lighting properties. In addition, the current heating system that is directly connected to the adjacent City Hall must also be replaced. This system is to be eliminated and the connection severed to create an independent system due to the different assigned uses for both buildings.

HVAC system

Existing elements related to HVAC systems will be replaced. The idea for the museum is to avoid the use of heat radiators and the use of underfloor heating in the existing timber structure (that will not be modified) as it is not technically viable. With these conditions, the option of an Air Handled Unit (AHU) that comprehends all the HVAC systems (ventilation, heating and cooling) was decided upon. This solution has advantages and disadvantages, the Air ducts will be larger and the AHU will have a bigger physical geometry. Nevertheless, only one system is necessary which is an advantage in this kind of buildings, where there is a lack of space. Nowadays, the presence of exposed air ducts in the occupied space is visually accepted if designed well and properly installed. Moreover, the maintenance will be easier due to the existence of a single system. The idea is to install an AHU with heat recovery at the exhaust side and by means of this device the efficiency of the system is enhanced. The two streams of air are passed through the core of the heat exchanger, where heat from the exhaupublic

st air is passed to the cooler incoming air. Hence, fresh air supplied to the building has already been pre-heated reducing the energy necessary to achieve the established conditions. The incoming air is then distributed evenly to all rooms and spaces by the duct work. A general scheme of the proposed system is represented in FIGURE 28, while FIGURE 29 contains a schematic picture of an Air Handled Unit.

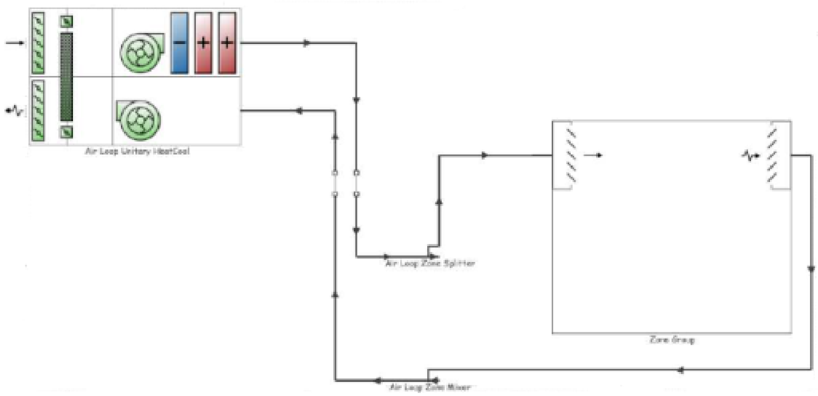


FIGURE 28: GENERAL SCHEME OF THE PROPOSED HVAC SYSTEM

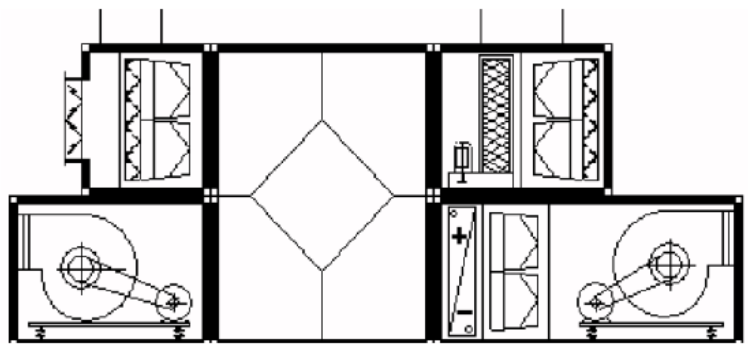


FIGURE 29: GRAPHIC REPRESENTATION OF THE AIR HANDLE UNIT

The AHU will be placed in the loft, room 13 according to FIGURE 7 and TABLE 2. Thus, this room will not be heated or cooled. The loads for the rest of the zones are calculated with the software EnergyPlus considering the renovation of the building envelope accorded with the Municipality. Hence, the HVAC system will be designed in line with the energy demand reduction that will be achieved by means of these actions.

TABLE 14: KAPITAIN ETXEA HEATING LOADS

Zone	Comfort T [ºC]	Steady-State Heat Loss [kW]	Design Capacity [kW]
Ground Floor			
Entrance + Reception	21.13	4.02	5.03
Storage	21.61	0.37	0.47
Bathroom 1	21.31	0.25	0.32
Bathroom 2	21.42	0.60	0.75
1st Floor + Mezzanine			
Main rooms + open spaces	21.26	6.90	8.63
2nd floor			
Main rooms + open spaces	21.16	6.62	8.27
Loft			
Utility room	8.24	0.00	0.00
		TOTAL	23.47 kW

TABLE 15: KAPITAIN ETXEA COOLING LOADS

Zone	Comfort T [ºC]	Humidity [%]	Design Capacity [kW]	Design Flow Rate [m3/s]	Cooling Load [kW]
Ground Floor					
Entrance + Reception	25.00	48.30	0.67	0.12	2.32
Storage	25.00	44.30	0.34	0.02	0.29
Bathroom 1	25.00	48.90	0.56	0.02	0.48
Bathroom 2	25.00	42.40	0.29	0.02	0.25
25.01st Floor + Mezzanine					
Main rooms + open spaces	25.00	51.00	5.29	0.22	4.60
2nd floor					
Main rooms + open spaces	25.00	50.20	5.29	0.23	4.60
Loft					
Utility room	---	---	0.00	0.00	0.00
		TOTAL	14.43	0.64	12.55

According with these loads the systems is selected and modelled in the software. It is defined by the following characteristics (see TABLE 16).

TABLE 16: HVAC SYSTEM SPECIFICATIONS

Controller - Outdoor Air

	Max. Outdoor Air Flow Rate [m³/s]	Min. Outdoor Air Flow Rate [m³/s]
AIR LOOP UNITARY HEATCOOL OUTDOOR AIR CONTROLLER	0.49	0.40

Heat Exchanger - Air to Air - Sensible and Latent

	Nominal Supply Air Flow Rate [m³/s]
AIR LOOP UNITARY HEATCOOL HEAT RECOVERY DEVICE	0.40

Coil – Cooling – DX- Single Speed

	Design Size Rated Air Flow Rate [m³/s]	Design Size Rated Total Cooling Capacity [m³/s]	Design Size Rated Sensible Heat Ratio	Design Size Evapor. Condenser Air Flow Rate [m³/s]
AIR LOOP UNITARY HEATCOOL DX COOLING COIL	0.49	12,137	0.68	1.38

Air Loop HVAC – Unitary Heat Cool

	Supply Air Flow Rate [m³/s]	Supply Air Flow Rate During Heating [m³/s]	Supply Air Flow Rate During Cooling [m³/s]	Supply Air Rate if no Cooling/ Heating [m³/s]
AIR LOOP UNITARY HEATCOOL	0.49	0.49	0.49	0.49
	Nominal Heating Capacity [W]	Nominal Cooling Capacity [W]	Maximum Supply Air Temp. [C]	Supplemental Nominal Capacity [W]
	29,377	12,137	50	12,137

Air Terminal – Single Duct -Uncontrolled

	Design Size Maximum Air Flow Rate [m³/s]
BATHROOM 1	0.02
BATHROOM 2	0.02
ENTRANCE + RECEPTION	0.16
STORAGE	0.01
1st FLOOR + MEZZANINE	0.17
2nd FLOOR	0.19

Branch

	Maximum Flow Rate [m³/s]
AIR LOOP UNITARY HEATCOOL MAIN BRANCHE	0.49

Air Loop HVAC

	Design Supply Air Flow Rate [m³/s]
AIR LOOP	0.49

Once the new HVAC system is defined it is possible to assess the total energy consumption of the renovated building (energy demand reduction + implementation of new HVAC system) considering the same parameters for the simulations.

TABLE 17TABLE 17: ENERGY CONSUMPTION IN KAPITAIN ETXEA reflects the final energy consumption of Kapitain Etxea once all the insulation measures and the new HVAC system are implemented:

TABLE 17: ENERGY CONSUMPTION IN KAPITAIN ETXEA

	Baseline [kWh]	Renovation [kWh]
Room electricity	409.91	409.91
Lighting	10,676.47	10,676.47
Pumps/Fans	287.68	3,058.28
Heating (gas)	54,383.13	0.00
Heating (electricity)	0.00	13,929.11
Cooling	642.41	3,108.63
TOTAL	**68,985.6**	**31,182.40**

Lighting system

Current lighting system has been described above. It is composed by different types of luminaries and lamps that are irregularly distributed. In fact, the installed power is very different in the three floors. The control is manual and the distribution irregular. Moreover, it has a considerable negative visual impact.

Despite the existing lamps and luminaries were replaced, the system would not be suitable for a museum; where the light must be distributed according to a new design. Therefore, the whole system must be replaced by a modern one, with better distribution, less visual impact and more efficient.

The new lighting system must be designed according to the Spanish and European Normal standards CTE – DB HE and UNE – EN 12464.1 The former establishes values for calculating the energy performance of the system (*Valor de Eficiencia Energética de la Instalación* in Spanish, VEEI) and the maximum values that can be accepted for each use of the building. The latter determines the average illuminance at the working plane (E_m) according to the use of the building. For a museum the VEEI is 5 W/m^2·100 luX and the E_m is 300 lux. This means that the installed power per area must be 15 W/m^2. In TABLE 18 it is shown how current values are below this figure, only ground plant exceeds it. Additionally it can be stated the power that must be installed in each area.

TABLE 18: INSTALLED LIGHTING POWER PER FLOOR

Floor	Area (m^2)	Currently installed power (W)	Currently installed power per area (W/m^2)	Installed power according to current standards (W)
Ground	109	2344	21,5	1635
First	109	1282	11,8	1635
Mezzanine	20	162	8,1	300
Second	109	986	9,1	1635

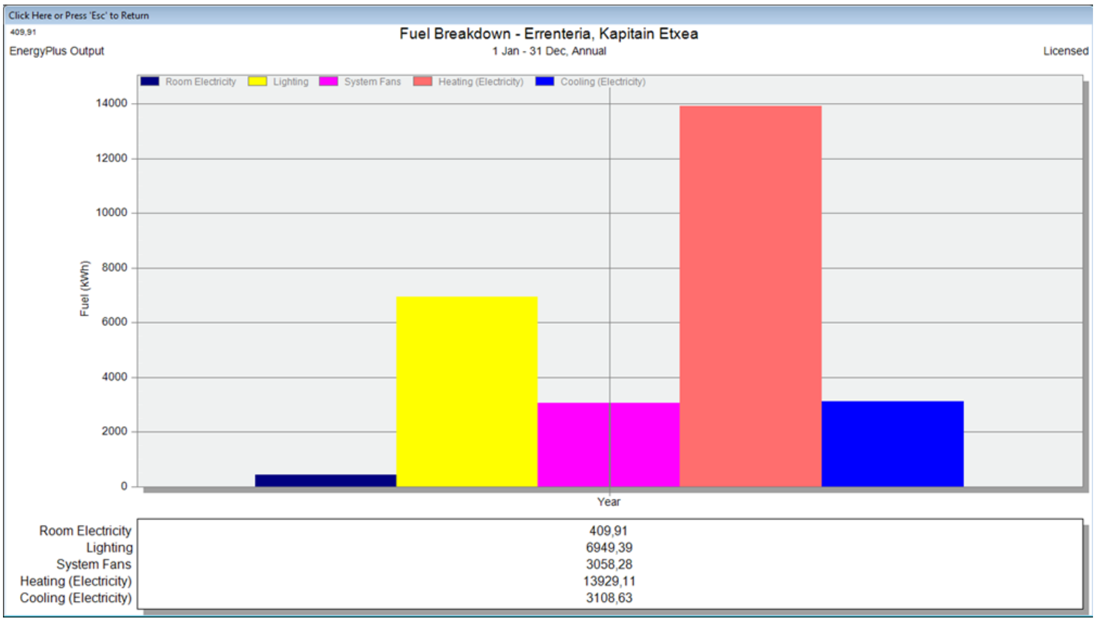


FIGURE 30: BREAKDOWN CONSUMPTION IN KAPITAIN ETXEA

With these new values it is possible to determine the energy consumption related to the renovation of the electric system: 6,949.39 kWh, as it can be seen in Renewable Energy Sources

PV Photo Voltaic (PV) panels

The renovation scheme includes the installation of 45 PV panels in the roof. Due to the small dimensions of the roof, it is not possible to install panels which supply a lot of power. It has been decided that the PV panels will be placed where the skylight is located. Despite it is not the best orientation, it is the area of the roof that is less affected by the shading from the adjacent buildings. By placing them in the existing opening it will reduce the visual impact.

Monocrystalline panels have been decided upon as they have a power of 121 Wp/m^2 with a efficiency rate of 0.15. As the panel will be placed over the hole of the skylight, it will have a surface of 28 m^2. Thus, the total installed power is 3.4 kWp.

According to the simulation done by EnergyPlus, and considering the effect of the shadings, this device will generate the following amount of electricity: 3,389 kWh per year.

TABLE 19: PV PANEL GENERATION PER MONTH

Month	Thermal Energy [kWh]
January	119
February	159
March	269
April	313
May	416
June	445
July	467
August	410
September	327

October	227
November	135
December	102
TOTAL	3,389

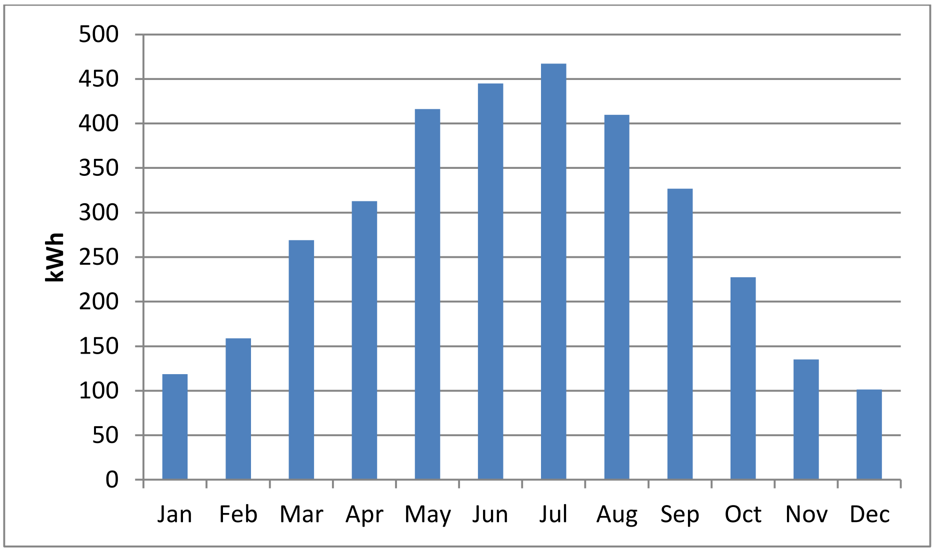


FIGURE 31: PV PANEL GENERATION PER MONTH

1.3.4. TOTAL IMPACT OF THE RENOVATION SCHEME

According to the results of the 3 proposed scenarios and the Municipality requirements, the third scenario was selected. The comparison of the first 2 scenarios proposed demonstrated that the second scenario lead to better energy performances. Nevertheless, the Municipality of Errenteria, due to technical criteria, mainly the reduction of useful space because of the installation of the insulation material on the inner space, was inclined for the third scenario. In addition, the Municipality decided to eliminate the skylight of the roof, which was used as useful space for the installation of a PV panel.

TABLE 20: SAVINGS AND NET ENERGY CONSUMPTION

	Baseline [kWh]	Renovation [kWh]	Savings [kWh]
Room electricity	409.91	409.91	0.00
Lighting	10,676.47	6,949.39	3,727.08
Pumps/Fans	2,873.68	3,058.28	-184.60
Heating (gas)	54,383.13	0.00	54,383.13
Heating (electricity)	0.00	13,929.11	-13,929.11
Cooling	642.41	3,108.63	-2,466.22
TOTAL	**68,985.60**	**27,455.32**	**41,530.28**
Generation	0.00	3,389	
TOTAL NET CONSUMPTION	**68,985.60**	**24,066.32**	**44,919.28**

According to the proposal, the total consumption of the renovated building will be the 40% of the baseline scenario and the total net consumption the 35%. This means that the renovation scheme will achieve 60% of savings in energy consumption and 65% of savings in net consumption.

The selected scenario is constituted by:

- Installation of walls (7 cm mineral wool), roof (10 cm PUR and vapour barrier) and ground floor (7 cm PUR, air gap and gravel) insulation;
- Windows replacement (4-16-4, low-e coated, air filled);
- Replacement of the lighting system by LED technology, with an installed power of 5,205 W;
- Installation of an Air Handling Unit, including ventilation with heat recovery, heating and cooling in the same system, with a Nominal Heating Capacity of 29,377 W and 12,137 W of Nominal Cooling Capacity;
- Installation of 3.4 kWp of PV panels on roof (28 m^2).

TABLE 21 shows the comparison between final energy, primary energy and CO_2 emissions in the base scenario and the selected renovation option.

TABLE 21: FINAL ENERGY, PRIMARY ENERGY AND CO_2 EMISSIONS

		Final energy [kWh]	Primary energy [kWh]	CO_2 Emissions [kg CO_2 /kWh]
Baseline	Gas	54,383.13	54,926.96	11,094.16
	Electricity	14,602.47	38,112.45	9,477.00
	TOTAL		**93,039.41**	**20,571.16**
Renovation	Gas	0.00	0.00	0.00
	Electricity	24,066.32	62,813.10	15,619.04
	TOTAL		**62,813.10**	**15,619.04**
Savings			**30,226.31**	**4,952.12**
			32%	**24%**

As it can be seen in TABLE 22, the 12.34% of energy is supplied by renewable energy systems.

TABLE 22: RENEWABLE SHARE

	Energy Consumption [kWh]	Energy Generation [kWh]	Energy Generation [%]
PV generation	27,455,32	3389	12.34

1.4. ECONOMIC EVALUATION OF THE PROPOSED RENOVATION SCHEME

The costs of the selected renovation options were determined by consulting catalogues and installers.

TABLE 23 presents the considered costs for the following renovation options:

- Installation of walls, roof and ground floor insulation
- Windows replacement (4-16-4, low-e coated, air filled);
- Replacement of the lighting system by LED technology, with an installed power of 5,205 W
- Installation of an Air Handled Unit, including ventilation with heat recovery, heating and cooling in the same system, with a Nominal Heating Capacity of 29,377 W and 12,137 W of Nominal Cooling Capacity
- Installation of 3.4 kWp of PV panels on roof (28 m^2)

TABLE 23: COSTS OF THE SELECTED RENOVATION OPTIONS

Renovation Scheme			
Concept	Dismantling	Equipment & Installation	TOTAL
Windows and balconies	524 €	12122 €	12646 €
Walls		4180 €	4180 €
Roof	144 €	18673 €	20817 €
Floor	3057 €	10170 €	13227 €
HVAC	-	21540 €	21540 €
PV	-	12602 €	12602 €
Lighting	-	26624 €	26624 €
TOTAL	**5725 €**	**105911 €**	**111636 €**

The renovation scheme of Kapitain Etxea proposed in this project should be intended as part of a deep renovation proposed for the reuse of the building. If we calculate the payback period of the intervention, it is very long and energy savings are not achieving the target proposed by the project. This is due because the actual building doesn't meet the comfort requirements to host a museum and should be adapted to its new use. Energy demand increase should be therefore considered as part of the renovation. The proposal has the intention of minimising this increase by proposing energy efficiency measures.

TABLE 24: ECONOMIC PARAMETERS OF THE RENOVATION

Energy savings	-9464 KWh
Energy price	0.14 €/kWh
Gas savings	54,383 kWh
Gas price	0.05 €/kWh
Costs	111.636 €
Savings	1394 €/year
Payback	80 years

2. CITY HALL

2.1. BUILDING GENERAL DESCRIPTION

2.1.1. LOCATION

Errenteria City Hall is an impressive building located at the heart of the city on the Herriko Plaza and is the administrative centre of the town. It was created through the merger of three existing buildings. The main building was erected in the 17th century and has a significant historic and aesthetic value and contributes to the urban landscape of the Old Town.

It is considered a "Conjunto Municipal" according to the Basque Government Decree 101/1996 of May 7th which means that it has special protection. The other two building that make up the complex have less relevance but contribute to the practical use of the building and overall streetscape. In 2000 the entire complex was extensively renovated according to a plan established in 1997. FIGURE 1 presents a general view of the whole building. It is possible to observe how the different constituent buildings can be identified by the diversity of façades.

FIGURE 32: ERRENTERIA CITY HALL – GENERAL VIEW FROM A CORNER OF THE HERRIKO PLAZA SQUARE

The 1997 project was undertaken to improve efficiency of the local government, facilitate circulation, structural stability and guarantee the unitary use of a single building. This entailed the erection of a new structure behind the original façades of the two less significant buildings retaining their scale, materials and openings. The more significant original and historic City Hall was also renovated.

FIGURE 33: PREVIOUS (LEFT) AND CURRENT STATE

The existing interior courtyard was kept as a key element of the plan yet covered with a skylight. The retention of this courtyard provided daylight to the interior office spaces.

A circulation and utility core was also erected in the place of a small single story building of minor relevance, as it can be seen in FIGURE 33. This new portion of the structure was necessary to make the three existing buildings function together.

This complex is located in the historic centre of the town (Erdialdea) and is of has similar scale, and materials characteristics of the other buildings in Errenteria. Three façades face Santa María Kalea street, Herriko Plaza square and Kapitanenea Kalea street. FIGURE 34 and FIGURE 35 present the location in the city map and aerial view.

TABLE 25: LOCATION DATA OF THE BUILDING

Address	Errenteriako Udaletxea, Herriko plaza, s/n - 20100 Errenteria, Gipuzkoa, Spain
Coordinates	43° 18' 45.93" N - 1° 53' 54.68" W
Google Maps	https://www.google.es/maps/place/Herriko+Plaza,+20100+Errenteria,+Gipuzkoa/@43.3128665,-1.8998091,424m/data=!3m1!1e3!4m2!3m1!1s0xd51a8a796551513:0x9a14cd1b49b216b9

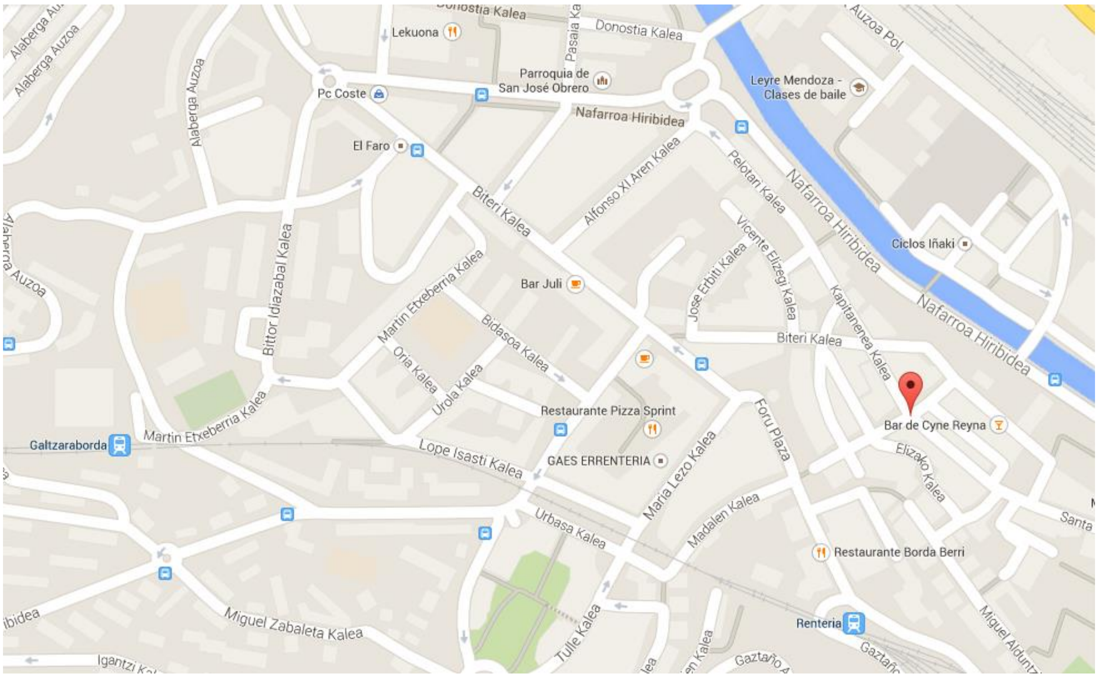


FIGURE 34: LOCATION IN THE CITY (MAP)

FIGURE 35: LOCATION IN THE CITY (AERIAL VIEW)

2.1.2. Shape and Orientation

FIGURE 36 presents the plan view of the ground floor and FIGURE 39 presents the aerial view of the complex. The building has a constant shape for all four floors with two mezzanines. The union of three building resulted in the presence of mezzanines, different levels in the same floor, three different stairs cores and small staircases of a few steps to make the vertical transitions. The joining of the three buildings also resulted in the integration of the existing courtyard as an atrium (FIGURE 37), which is covered by a skylight.

The City Hall complex is very close to Kapitain Etxea, another municipal building outlined in this study. This is important because they share the same gas-fired boiler used for heating.

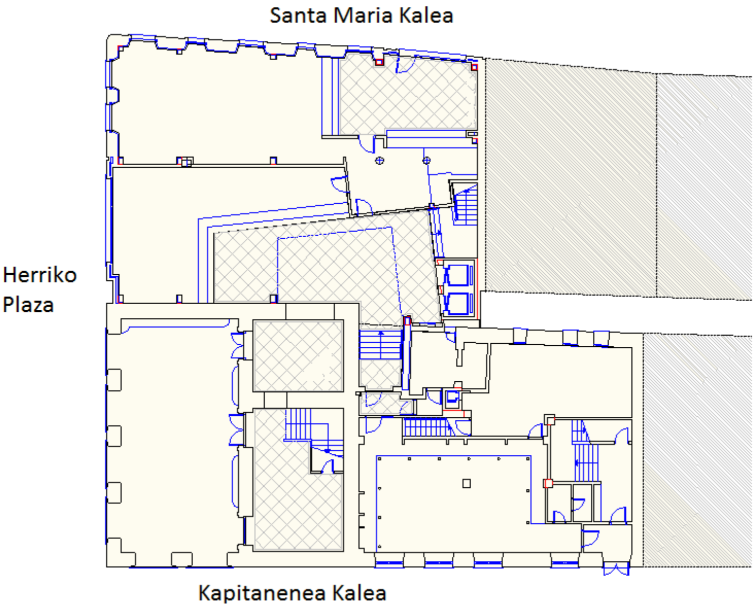


FIGURE 36: CITY HALL'S GROUND FLOOR PLAN VIEW

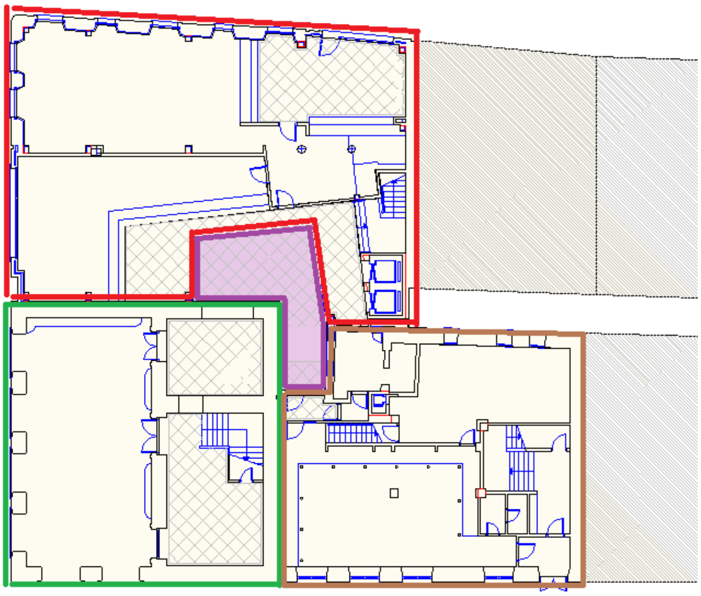


FIGURE 37: APPROXIMATE BOUNDARIES OF THE FORMER BUILDINGS. IN PURPLE THE COURTYARD

FIGURE 38 presents two different perpendicular cross sections observed from the same orientation. The particularities caused by the merge of three buildings can be observing in these drawings.

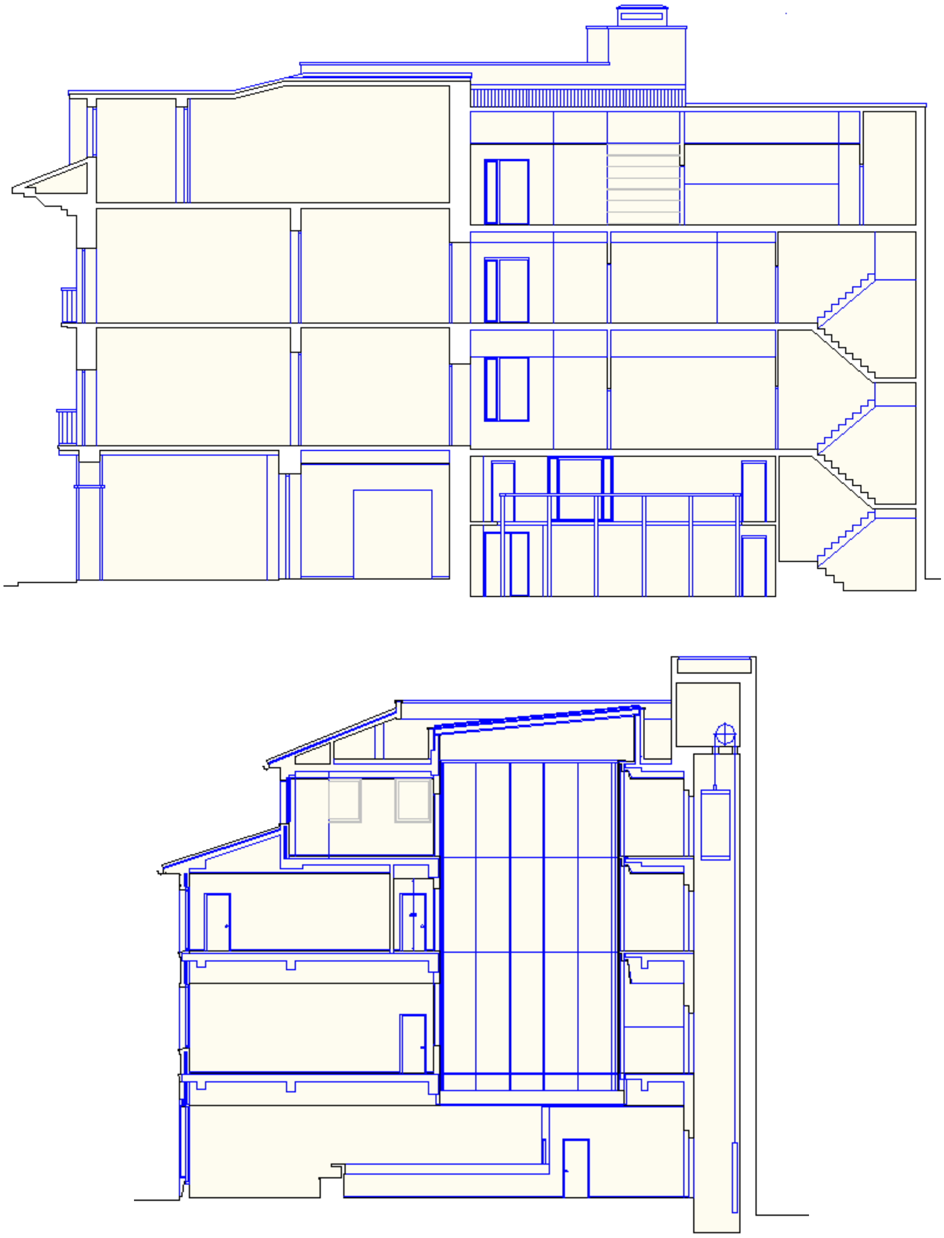


FIGURE 38: CROSS SECTION

This last figure also helps to describe how there are different levels for the same floors. There are several combinations of vertical cross sections.

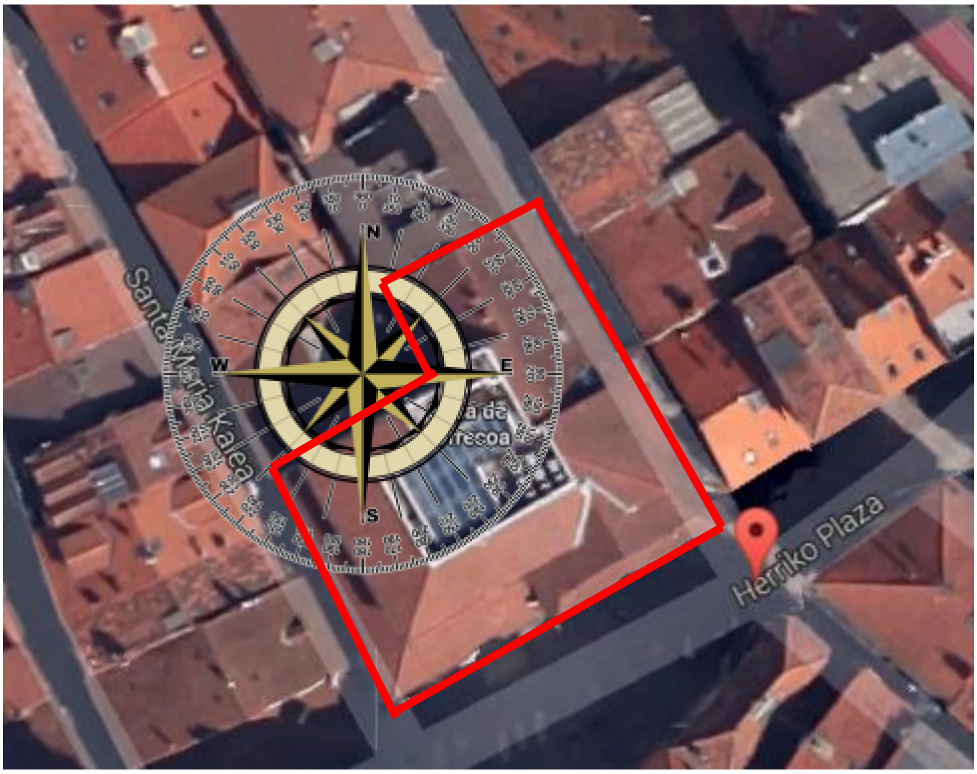


FIGURE 39: AERIAL VIEW

As can be seen in FIGURE 39 the main façade of the building is oriented with an axis of 60º oriented to SouthEast and placed in the Herriko Plaza (Popular square).

2.1.3. Area and Volume

The building has total area of about 2,961 m^2 with a total usable surface of about 2,253 m^2 (non-occupied loft) and a volume of 11,418 m^3.

In TABLE 26 the data related to constructed and useful surface and volume is represented per floor. It can be observed how the surface areas of the first and second floors are very similar (in the ground floor the arcade is not considered a usable office space for this study). The plan view has few differences in those levels. However, there is an evident decrease of surface area on the third floor. This is caused by the pitched roofs, as it can be observed in FIGURE 38.

As can be seen in FIGURE 38, the roof is formed by several pitched gables placed at different levels and includes a flat part. All the gables are tiled and drain via gutters and downspouts to the street and city storm water system. The flat portion of the roof behind the roofs holds the Heating Ventilation and Air Conditioning (HVAC) equipment and the skylight that covers the atrium/courtyard.

TABLE 26: USEFUL SURFACE AND VOLUME PER FLOOR

Floor	Constructed Surface	Useful Surface	Volume
Ground Floor	705.8	484.3	2,749.9
Ground (mezzanine)	128.4	84.1	288.8

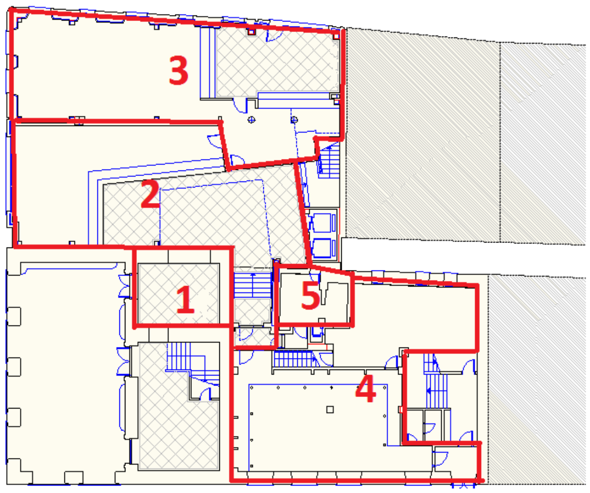
First	695.6	548.9	2,851.8
Second	156.1	563.6	2,790.3
Second (mezzanine)	697.6	111.1	380.1
Third	577.6	460.4	2,356.6
TOTAL	2,960.9	2,252.6	11,418.4

2.1.4. Current Use

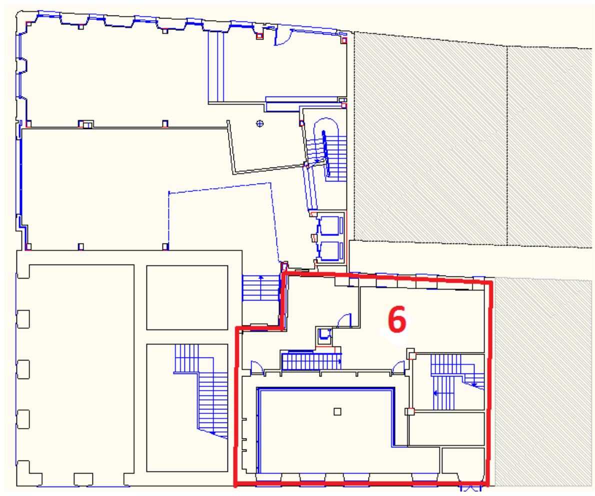
The building is used for administrative activities, offices, Errenteria resident meetings and presentations. The municipal management of the city is conducted from this complex.

TABLE 27: CURRENT USE, USE PROFILE AND TIMETABLE AND NUMBER OF USERS

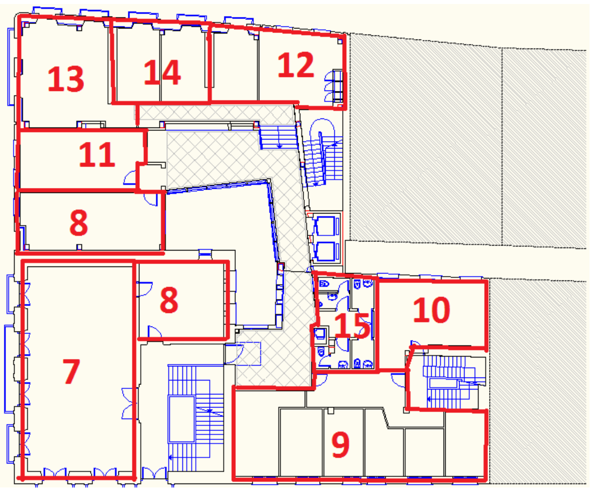
Use area			Use Profile – Number of Users	Timetable
Ground Floor	1	Access control	Public access/municipal employees – 1	7:00-15:00
	2	Information and register	Public access/municipal employees – 8	7:00-15:00
	3	Fiscal office	Public access/municipal employees – 10	7:00-15:00
	4	Archive	Public access/municipal employees – 4	7:00-15:00
	5	Boiler Room	Private access	---
Ground (mezzanine)	6	Archives	Private access	---
First Floor	7	Chapter house	Meetings – 10/100	Occasionally
	8	Meeting rooms	Municipal employees – 14	7:00-18:00
	9	Political parties rooms	Public access/municipal employees – 2/6	7:00-18:00
	10	Archive	Private access	---
	11	Multifunctional room	Municipal employees – 6	7:00-18:00
	12	Basque language area	Municipal employees – 6	7:00-15:00
	13	Equality area	Municipal employees – 1	7:00-15:00
	14	Hiring area	Municipal employees – 1	7:00-15:00
	15	Toilets	Public access/municipal employees – 2	7:00-18:00
Second Floor	16	Mayor's office	Municipal employees – 2	7:00-18:00
	17	Staff room	Municipal employees – 6	7:00-15:00
	18	Inland revenue	Municipal employees – 9	7:00-15:00
	19	Offices area	Municipal employees – 3	7:00-15:00
	20	State area	Municipal employees – 5	7:00-15:00
	21	Staff delegate	Municipal employees – 1	7:00-15:00
	22	Deputy mayor's office	Municipal employees – 1	7:00-18:00
	23	Meeting rooms	Municipal employees – 6	7:00-18:00
	24	WCs and cleaning staff	Municipal employees – 2	7:00-18:00
Second Floor (mezzanine)	25	Office	Municipal employees – 4	7:00-15:00
	26	Committee room	Municipal employees – 2	7:00-15:00
	27	Informatics area	Municipal employees – 6	7:00-15:00
Third Floor	28	Administrative area	Municipal employees – 6	7:00-15:00
	29	Urbanism area	Municipal employees – 8	7:00-15:00
	30	Meeting rooms	Municipal employees – 3	7:00-15:00
	31	Delineation	Municipal employees – 3	7:00-15:00
	32	Toilets	Municipal employees – 2	7:00-15:00



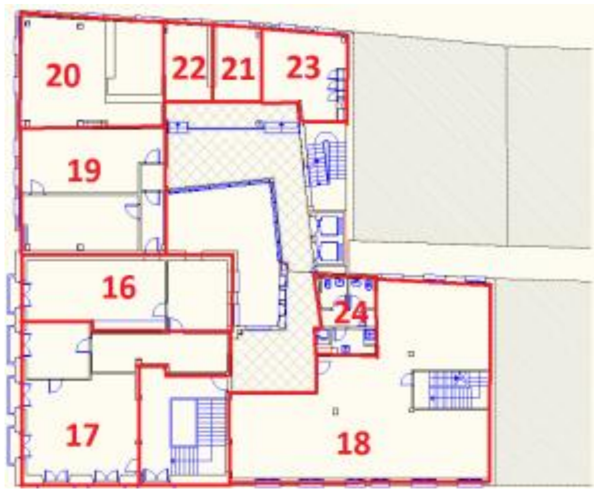
Ground Floor



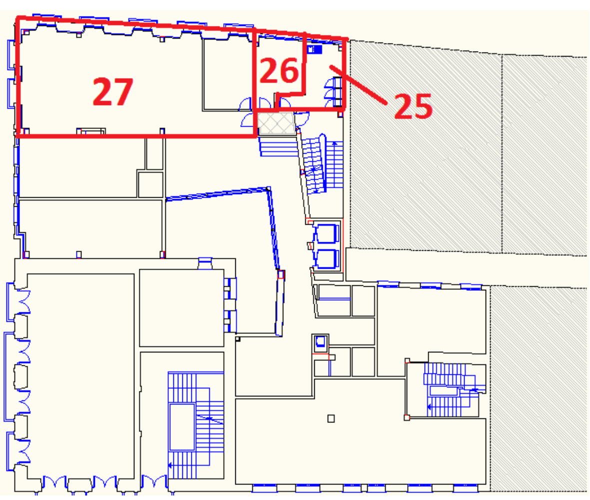
Ground (mezzanine)



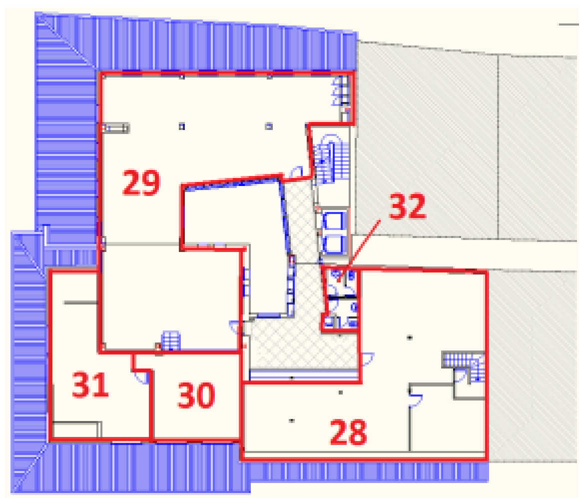
First Floor



Second Floor



Second Floor (mezzanine)



Third Floor

FIGURE 40: CITY HALL DISTRIBUTION

2.2. Current Building Conditions

2.2.1. Constructive Building Characteristics:

Envelope Elements

Due to the extensive renovations that were carried out in 2000, the building characteristics are already very suitable for the aim of nZEB buildings. Therefore it is not expected to significantly reduce the energy demand of the building by altering the composition of the envelop elements or materials.

Walls

The walls of the historical building have a total surface of 548 m^2, of which 122 m^2 or 22.2% are windows. The walls of the other existing building have a total surface of 194 m^2, of which 87 m^2 or 44.8% are for windows. Finally, the walls of the newer portions of the building have a total surface of 156 m^2, of which 56 m^2 are windows (35.8%). In total, the external walls of the whole building have a total surface of 899 m^2, of which 266 m^2 or 29.6% are windows.

The external walls are made of two brick layers separated by an air gap partially filled with insulating material (PUR). This gap has a thickness of 30 to 32 cm. In the case of the historical building, the walls' typology is sandstone masonry, internally insulated with projected PUR and a final render of gypsum. These walls have a thickness of 80 to 86 cm.

Roof

Due to the special history and evolutions of the building there are several roofs in the complex. It can be distinguish two typologies: pitched and flat roofs.

The pitched roofs are located at two different levels (third floor and roof level) and they are formed by a concrete slab, with waterproof layer and insulation material (Projected PUR). These elements are covered by tiles placed over wood sleepers. The thickness of pitched roofs is 33 cm. The total surface of all the pitched roofs is 448 m^2.

The flat roof is similar, but in this case instead of ceramic tiles, the roof´s final covering is concrete paving tile. Thickness of the flat roof: 38 to 42 cm. It has a surface of 247 m^2, of which 46 m^2 is a skylight (18.6%).

Slab on Ground

This important part of the envelope was also renovated. It is a suspended ground floor formed by different layers of gravel, breeze blocks, waterproofing layers, projected PUR, concrete slabs, cement renders and finally granite stone tile. The total thickness is 56 cm.

Windows and balconies

All the windows frames are made of treated wood. All the windows are double glazed (4+16+4) with air chamber with the exception of the six windows in the chapter house (first floor). This typology is represented in FIGURE 41.

FIGURE 41: TYPOLOGY OF THE FENESTRATIONS

In the main façade, that oriented to the southeast:

- 8 operable balconies 1.55 x 2.90 m
- 6 operable windows with 1.00 x 2.10 m
- 4 operable windows with 1.20 x 2.20 m
- 4 operable windows with 1.00 x 1.40 m
- 4 operable windows with 1.00 x 1.40 m
- 2 operable windows with 1.80 x 1.40 m
- 2 operable windows with 1.00 x 1.00 m
- 1 operable window with 1.60 x 1.30 m
- 2 fixed windows with 1.40 x 1.90 m
- 1 fixed window with 2.60 x 4.70 m

In the façade oriented to the northeast:

- 8 operable windows 1.55 x 1.50 m
- 6 operable balconies 1.55 x 2.90 m
- 4 operable windows with 1.10 x 1.50 m
- 4 operable windows with 1.50 x 2.00 m
- 3 operable windows with 1.40 x 2.00 m
- 1 operable window with 1.45 x 1.50 m

In the façade oriented to the southwest:

- 10 operable windows 1.00 x 2.25 m
- 7 operable balconies 1.00 x 0.90 m
- 6 operable windows with 1.00 x 1.40 m
- 4 operable windows with 1.00x 1.30 m
- 3 fixed windows with 1.30 x 1.90 m
- 2 fixed windows with 0.90 x 1.90 m
- 1 fixed window with 2.00 x 2.60 m

In the façade oriented to the small courtyard:

- 8 operable windows 1.20 x 1.60 m

- 2 operable windows 0.80 x 1.60 m
- 2 operable windows 0.70 x 1.60 m

Additionally, in the roof are the following openings:

- 1 fixed skylight of 46 m^{2}.
- 4 operable windows 1.00 x 0.65 m
- 3 operable windows 1.00 x 1.20 m
- 1 operable window 1.00 x 1.30 m

The typology of the skylight is shown in FIGURE 42.

FIGURE 42: SKYLIGHT

All the windows and balconies have interior aluminium venetian blinds. According to the conservation plan, the openings (fenestrations) are not listed for special historic protection. There are no external shading devices for any of the windows or openings. Important shading is also ensured by adjacent and close buildings (narrow streets due to the urban pattern). There are four doors in the whole building. One is made of wood while the rest are made of glass. Only two of them are frequently used.

Airflows and Pathologies

The building does not present major airflow infiltration from outside. As previously mentioned, the envelope was renovated in 2000 and it has been kept in good condition since then. It can be observed that the building is regularly maintained. The glass doors are controlled automatically and they are not constantly opened. The fenestrations of the Chapter Room in the historic building, despite being old, are well preserved.

It must be commented that most of the windows are operable. This means that they can be opened by the users when they want, so the thermal behaviour of the building can be altered drastically by the decisions of the users.

2.2.2. ENERGY SYSTEMS

HVAC

VENTILATION SYSTEM

There is forced air ventilation system in the following areas: information office, register, fiscal office, toilets (of all floors) and atrium. It is made up of three independent systems:

- Information office, register and fiscal office (ground floor):
  Double-flow unit with heat recovery.
  Model: CIAT/DF.P-800
  Flow rate. 1500 m^3/h
  Nominal power: 870 W / 380 V.
  Working scope: -10º C +40º C / 0-80% HR

- Atrium:
  Double-flow unit.
  Model: Samp 34670
  Flow rate. 1500 m^3/h (610Pa)
  Nominal power: 2750 W / 400 V.

- Toilets:
  Single-flow unit.
  Model: Soler & Palau / Direct-Air ILB/4-225
  Flow rate. 850 m^3/h (350 Pa)
  Nominal power: 520 W / 220 V.

HEATING SYSTEM

The heating system is designed to heat all the rooms of the building. The system is basically formed by heat radiators that are warmed by hot water produced by a gas boiler placed in the Ground Floor. It is a centralised system that can be independently regulated at the different areas.

The boiler is activated by an exterior sensor that measures the outdoor temperature. The hot water is distributed to all the floors through vertical insulated pipes. Then the water is directed to the heat radiators which are controlled by electro thermic valves connected to thermostats. These elements regulate the temperature according to the users' needs, with manual controls.

The heat radiators are made by cast iron of three columns and have different dimensions according their location within the building and size of the space. These dimensions were chosen according to the calculated thermal loads in the renovation project.

The system also supplies hot water to Kapitain Etxea, another municipal building. However, the consumption is negligible as this building houses the city archives and is not regularly occupied. The gas boiler is a model of the brand Roca and it has a COP of 0.88 and total power of 232.6 kW.

FIGURE 43: HEAT RADIATORS

FIGURE 44: THERMOSTAT OF THE HEATING SYSTEM

COOLING SYSTEM

As with the ventilation system, the cooling system is divided in independent phases.

PHASE 1

This subsystem cools the administrative area of the Third Floor (area 28). It is a double-flow air to air system, with one condenser coil in the roof and the evaporator coil that is placed in the ceiling of the cooled area. The cooled air is distributed by means of air conducts.

Model: Mitsubishi Electric PE-10YB
Flow rate: 13,200 m^3/h
Cooling power: 29,300 W
Nominal power: 13,000 W
Working scope: -10º C +40º C / 0-80% HR

PHASE 2

It is a varied refrigerant volume (VRV) solution formed by 8 condenser units placed in the roof. Each condenser unit can be connected to 7 evaporator units. Each evaporator unit is independent within the set linked to the condenser unit and it is controlled manually by means of a remote control. Additionally the eight condenser units are controlled by timers that limit their working period to the timetable of the City Hall.

FIGURE 45: CONDENSER UNITS OF THE PHASE 2

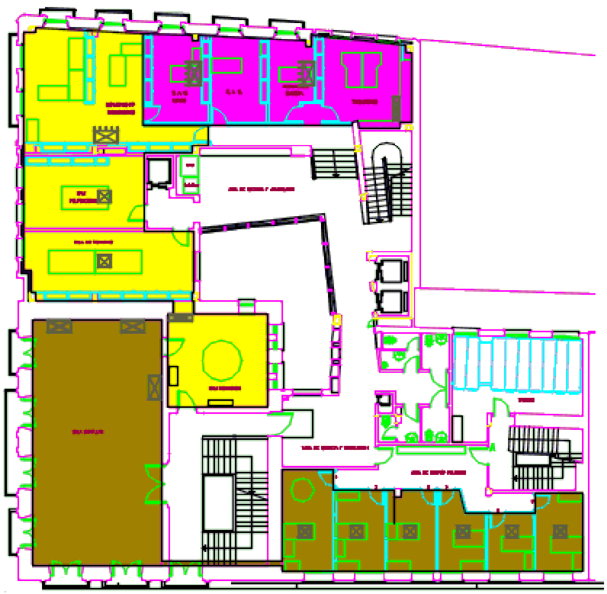
FIGURE 46: DIFFERENT TYPES OF EVAPORATOR UNITS

The eight condenser units are placed on the roof. They are compact devices that are formed by the compressor, the expansion valve and the condenser unit. Inside the building there are the evaporator units and the pipes filled with refrigerant, no air ducts are used.

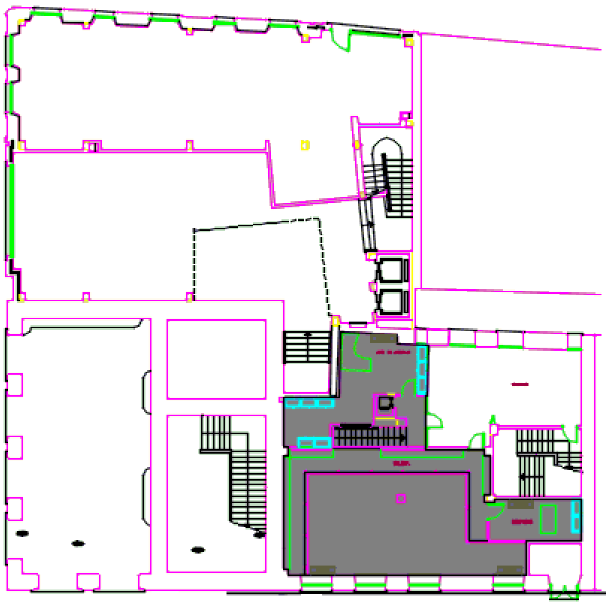
FIGURE 47: TIMERS THAT CONTROLS THE CONDENSER UNITS ON THE ROOF

The condenser units are controlled by timers. They work from 6 am to 8 pm; this is a rudimentary system that switches off the condenser units at the end of the working day if a user forgets to switch off the equipment before leaving the building. Each evaporator unit is directly controlled by the user by means of remote controls. This means that Phase 2 is manually controlled.

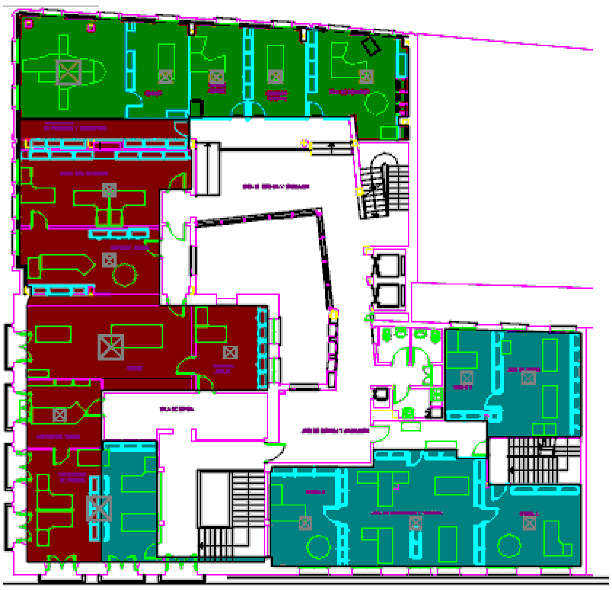
The area of influence of each set is shown in FIGURE 48 by colours.



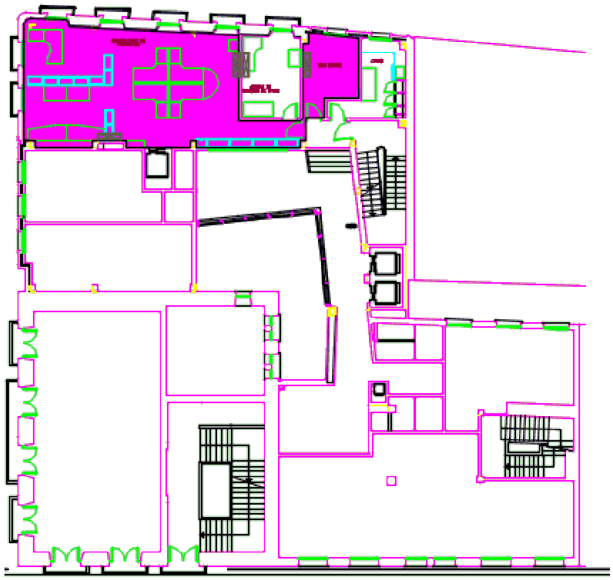
First Floor



Mezzanine (Ground Floor)



Second Floor



Mezzanine (Second Floor)

Third Floor

Set 1 Set 2 Set 3 Set 4

Set 5 Set 6 Set 7 Set 8

FIGURE 48: DISTRIBUTION OF THE DIFFERENT SET OF THE COOLING SYSTEM

The sets are placed and formed by:

Set 1:

8 Evaporator units: 648 W

1 Condenser unit: 2,530 W

Set 2:

8 Evaporator units: 648 W

1 Condenser unit: 2,530 W

Set 3:

7 Evaporator units: 567 W

1 Condenser unit: 2,530 W

Set 4:

6 Evaporator units: 488 W

1 Condenser unit: 2,530 W

Set 5:

7 Evaporator units: 567 W

1 Condenser unit: 2,530 W

Set 6:

5 Evaporator units: 405 W

1 Condenser unit: 2,530 W

Set 7:

9 Evaporator units: 729 W

1 Condenser unit: 2,530 W

Set 8:

4 Evaporator units: 324 W

1 Condenser unit: 2,530 W

Lighting

The lighting system was also installed in 2000 so it can be considered as modern. Nevertheless, the control of the lighting is mainly controlled locally without any automatic control, which allows some lighting circuits to remain on without being needed. For example, in circulation areas with enough natural lighting the lights remain on for a long time.

TABLE 28: LIGHTING SYSTEM PER FLOOR

Floor	Type of light	Power (W)	Number	Total Power (W)	Total installed lighting power per floor (W)
Ground Floor	Fluorescent Compact TC	2x36	29	2088	3620
	Fluorescent Linear T8	1x36	4	144	
	Fluorescent Linear T8	1x58	6	348	
	Fluorescent Linear T8	2x58	2	232	
	Fluorescent Compact TC	2x9	36	648	
	Halogen Downlight	1x80	2	160	
Ground (mezzanine)	Fluorescent Compact TC	2x36	8	576	1300

	Fluorescent Linear T8	1x58	10	580	
	Fluorescent Compact TC	2x9	8	144	
First Ground	Fluorescent Compact TC	2x36	44	3168	5088
	Fluorescent Linear T8	1x58	9	522	
	Fluorescent Compact TC	2x9	51	918	
	Halogen Downlight	1x80	6	480	
Second Ground	Fluorescent Compact TC	2x36	75	5400	6898
	Fluorescent Compact TC	2x9	61	1098	
	Halogen Downlight	1x80	4	320	
	Fluorescent Compact TC	1x80	1	80	
Second Ground (mezzanine)	Fluorescent Compact TC	2x36	18	1296	1476
	Fluorescent Compact TC	2x9	10	180	
Third Ground	Fluorescent Compact TC	2x36	46	3312	6152
	Fluorescent Linear T8	1x36	27	972	
	Fluorescent Linear T8	1x58	6	348	
	Fluorescent Compact TC	2x9	25	450	
	Halogen Downlight	1x80	4	320	
	Halogen Projector	1x150	5	750	
Loft	Fluorescent Linear T8	1x58	6	348	652
	Fluorescent Linear T8	2x58	2	232	
	Fluorescent Compact TC	2x36	1	72	
				TOTAL	25186

FIGURE 49: FLUORESCENT COMPACT TC 2X36W (LEFT) AND FLUORESCENT COMPACT TC 2X9W (RIGHT)

Luminaries are perfectly inserted in the suspended ceilings (see FIGURE 49). Moreover, they have been recently installed and present modern features. Hence, their replacement is not needed. The efficiency of the lighting system could be improved by replacing the existing fluorescent lamps by LED technology and improved controls.

ICT

Most of the offices and rooms have computers and printers and there is a room with a central computer servers and an internal circuit camera system (CCTV) for security. There are photocopier machines and video projectors in some rooms.

TABLE 29: ICT EQUIPMENT PER FLOOR

Use area			Equipment
Ground Floor	1	Access control	2 PCs
	2	Information and register	8 PCs – 2 printers
	3	Fiscal office	11 PCs – 3 printers
	4	Archive	2 PCs
	5	Boiler Room	---
Ground (mezzanine)	6	Archive	1 PC – 1 printer
First Floor	7	Chapter house	---
	8	Meeting rooms	---
	9	Political parties rooms	5 PCs
	10	Archive	---
	11	Multifunctional room	1 PC
	12	Basque language area	3 PCs – 1 printer
	13	Equality area	2 PCs – 2 printers
	14	Hiring area	2 PCs
	15	WCs	---
Second Floor	16	Mayor's office	2 PCs – 2 printers
	17	Staff room	4 PCs – 1 printer
	18	Inland revenue	9 PCs – 1 printer
	19	Offices area	4 PCs – 1 printer
	20	State area	4 PCs – 1 printer

	21	Staff delegate	1 PC
	22	Deputy mayor's office	1 PC
	23	Meeting rooms	---
	24	WCs and cleaning staff	---
Second Floor (mezzanine)	25	Office	3 PCs – 1 printer
	26	Committee room	---
	27	Informatics area	10 PCs – 2 printers
Third Floor	28	Administrative area	8 PCs – 1 printer
	29	Urbanism area	11 PCs – 2 printers
	30	Meeting rooms	1 PC
	31	Delineation	4 PCs – 2 printers
	32	WCs	---

It is considered that each PC (or laptop) has an average power of 150 W and each printer 50 W in standby. Additionally, the central computer server has a maximum power of 700 W.

Others

The building has three lifts; one of them is actually a service lift that connects the ground floor with the mezzanine of the first floor.

2.2.3. Energy Consumption & Energy Generation

Electricity

The building receives electricity in Low Voltage, three-phase system of 380 V, with a maximum contracted power of 45 kW. The Municipality has contracted a tariff option that divides the day in three periods: on-peak, mid-peak and off-peak. The distribution of these three periods changes from winter to summer (see TABLE 31).

TABLE 30: SCHEDULE OF THE TARIFF PERIODS

Timetable	Tariff
WINTER	
00:00 - 08:00	Off- peak
08:00 - 18:00	Mid- peak
18:00 – 22:00	On - peak
22:00 – 24:00	Mid - peak
SUMMER	
00:00 - 08:00	Off- peak
08:00 – 11:00	Mid- peak
11:00 – 15:00	On - peak
15:00 – 24:00	Mid - peak

In 2014 the building had an electricity consumption of 146,541 kWh and an associated cost of about 23882 €. It is necessary to underline that in the final cost there are considered aspects such as tariff periods, contracted power, equipment rental and VAT. The power consumption along the year can be checked in the graph included in FIGURE 50, while the distribution between tariff periods is presented in FIGURE 51.

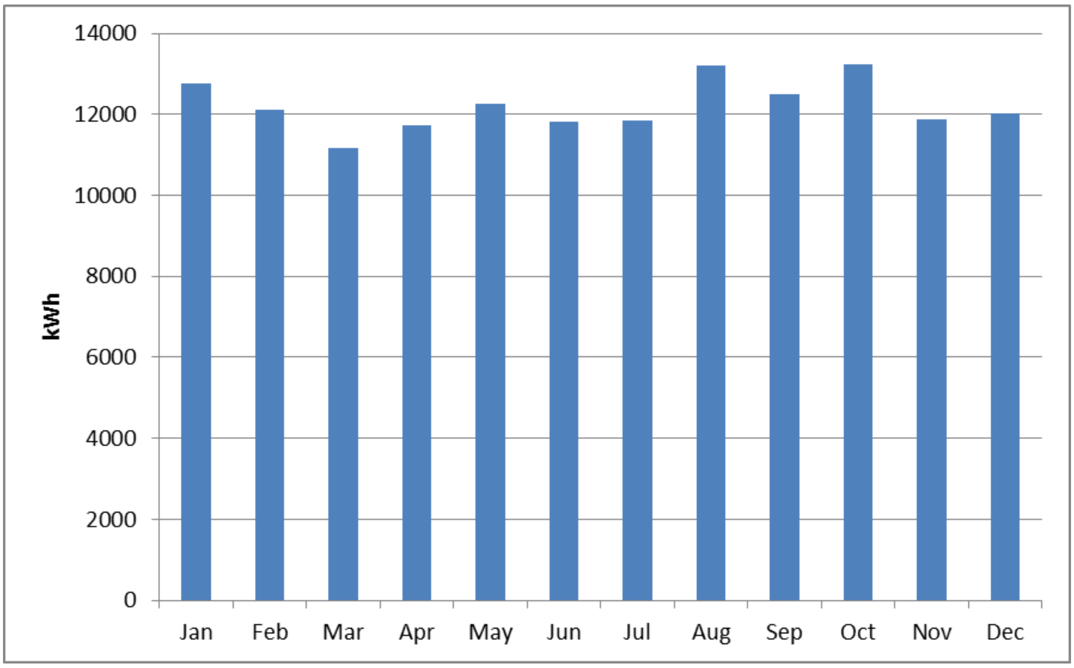


FIGURE 50: MONTHLY CONSUMPTION OF ELECTRICITY

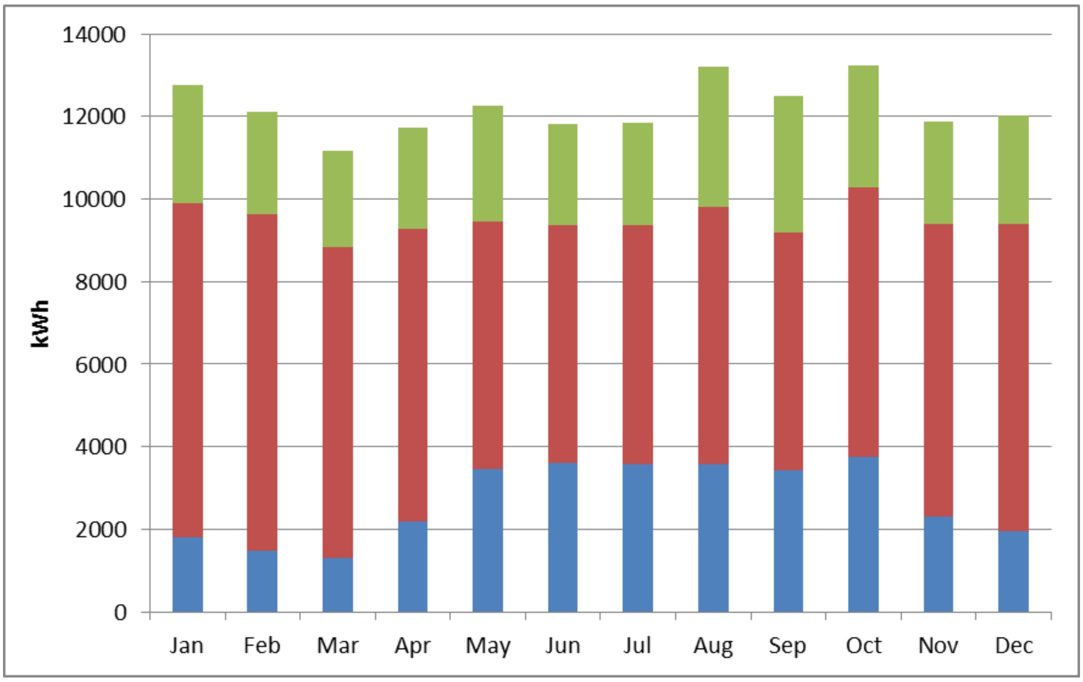


FIGURE 51: MONTHLY DISAGGREGATION BETWEEN TARIFF PERIODS

As can be observed, there is a slight increase in the electric consumption during the summer, this is caused by the typology of the building system. As the cooling system is electric, the demand increases during the summer. On the other hand, the heating system is supplied by a gas boiler, so the consumption of this system is not reflected in the electrical consumption.

The differences in FIGURE 51 are caused by the change of the tariff schedule from summer period to winter period.

The disaggregation of electricity consumption between uses has not been defined due to the lack of consumption monitoring. Due to the use of the building the consumption is mainly divided between 3 major uses: lighting, Information and Communication Technology (ICTs) and Heating Ventilation and Air Conditioning (HVAC).

Gas

The heating system is supplied by a natural gas-fired boiler that is located on the Ground Floor. This gas boiler also supplies hot water for the heating system of Kapitain Etxea, which is nearby. The hot water travels to this other building through underground pipes below Kapitanenea Kalea (street). However, this building has not currently a regular use, so its heating system is not frequently operated

In TABLE 31 the gas consumption from December 2012 to November 2013 is shown.

TABLE 31: GAS CONSUMPTION IN THE PERIOD DECEMBER 2012-NOVEMBER 2013

Year	Month	Thermal Energy [kWh]	Thermal energ [kWh/m^2]y	CO_2 Emissions [kgCO_2]
2012	December	14,590	1.16	2,941
2013	January	29,260	2.32	5,889
	February	41,251	3.27	8,316
	March	23,349	1.85	4,707
	April	18,671	1.48	3,764
	May	6,039	0.00	1,217
	June	0	0.00	0
	July	0	0.00	0
	August	0	0.00	0
	September	0	0.00	0
	October	38	0.00	8
	November	12,800	1.02	2,580
	TOTAL	131,408	10.42	10,42

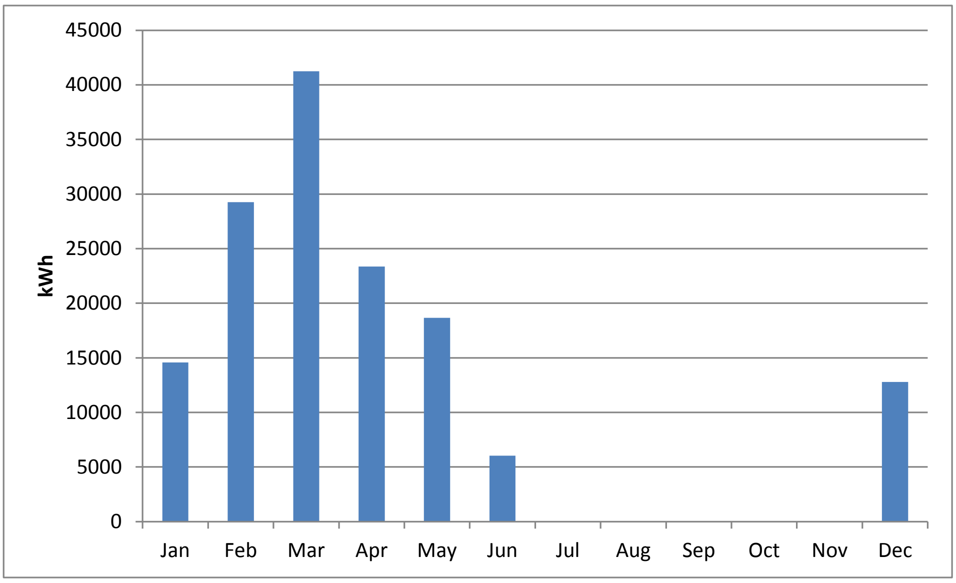


FIGURE 52: MONTHLY CONSUMPTION OF GAS

The average cost of gas was 0,055 €/kWhPCS. So the energy consumption in the gas-fired boiler for the whole year was 7.227 €.

Renewable Energy Source (RES)

Currently, the building does not have any renewable energy source.

Others

The building does not have any other source of heat or electricity generation such as solar panels.

Final Energy Consumption and CO_2 Emissions

During 2014 the buildings had an electricity consumption of 146,541 kWh. Additionally, there was a consumption of 131,408 kWh of natural gas, being the total energy consumption 277,949 kWh.

TABLE 32 presents the main energy parameters of the building which were considered as baseline. Such parameters were assessed considering the following conversion factors:

- Electricity to primary energy – 2.61 kWh E. primary /kWh E. final
- Natural gas to primary energy – 1.01 kWh E. primary /kWh E. final
- Electricity to CO_2 emissions – 0.649 kg CO_2 /kWh E. final
- Natural gas to CO_2 emissions – 0.244 kg CO_2 /kWh E. final

TABLE 32: ENERGY PARAMETERS

	Final Energy kWh	Energy Dens. kWh/m^2	Primary Energy kWh	CO_2 Emissions kg CO_2 /kWh
Electricity	146,541	65.1	382,472	95,105
Gas	131,630	58.3	132,722	32,118
Total	277,949	123.4	515,194	127,223

2.3. Renovation Scheme

2.3.1. Aim of the renovation plan

The aim of the overall project is to achieve an average primary energy reduction between 75% and 80% of the current demand and to ensure that between 50% and 90% of the consumed energy is generated by renewable energy sources installed in the building.

Since the building was extensively renovated in 2000, the possibilities to meet this goal and reduce the energy demand are seriously limited. As has been underlined there was an important reduction in the thermal transmittance of the buildings envelope (walls, roof and openings) and the existing systems (lighting and HVAC) are relatively modern.

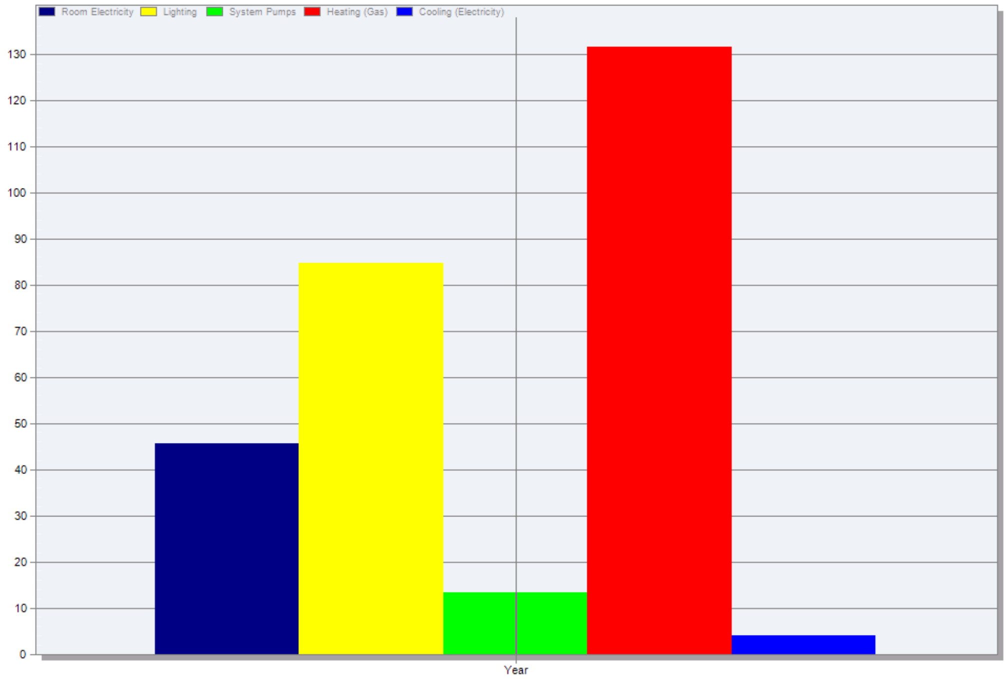


FIGURE 53: ENERGY CONSUMPTION OF THE CITY HALL ACCORDING TO ENERGY PLUS

In FIGURE 53 and TABLE 33 the energy consumption of the City Hall obtained in the Energy Plus software program simulation is shown. It can be observed how heating and lighting present the higher figures. On the other hand, the cooling system has little relevance in the total consumption. Therefore, the renovation scheme will be focused in lighting and heating systems.

TABLE 33: ENERGY CONSUMPTION OF THE CITY HALL ACCORDING TO ENERGY PLUS

System	Energy [MWh]
Room electricity	45.58
Lighting	84.76
Ventilation	13.26
Heating (gas)	131.63
Cooling	3.93

The geometry and location of the building will be a serious constraint for the implementation of renewable energy sources. The building has an important and consistent use and all the rooms have well-defined uses. Therefore there is no place for additional equipment inside the building. This must be considered to select the type of Renewable Energy System (RES).

Additionally, the building is located in the Old Town of Errenteria, an area with narrow streets and an irregular pattern. The presence of buildings close to the City Hall, especially the church, reduces the sun incidence on the roofs of the building. In addition the original building has significant historic value and cannot be extensively altered.

2.3.2. Energy demand Reduction

Usually the energy demand reduction is achieved by improving the typology of the building envelope. Walls, roof and windows present acceptable thermal transmittance values so their improvement would entail investments with low real impact in the energy demand reduction.

Opaque envelope

TABLE 34: DIFFERENT EXISTING TYPOLOGIES FOR PARTS OF THE OPAQUE ENVELOPE

Part of envelope	Typology	Characteristics
Wall of the historic building	*Outer surface* - 600mm sandstone - 30mm projected PUR - 20mm gypsum *Inner surface*	R-Value: 1.32 m^2K/W U-Value: 0.76 W/m^2K
Wall of the renovated building	*Outer surface* - 15mm mortar render - 150mm sandstone - 30mm projected PUR - 40mm air gap - 90mm hollow brick - 15mm plasterboard *Inner surface*	R-Value: 1.6 m^2K/W U-Value: 0.60 W/m^2K
Roof	*Outer surface* - 20mm ceramic tile - 40mm air gap - 10mm roofing asphalt - 30mm PUR - 200mm concrete flooring *Inner surface*	R-Value: 2,581 m^2K/W U-Value: 0,387 W/m^2K
Ground floor paving	*Outer surface* - 200mm concrete - 90mm concrete block - 40mm concrete - 10mm PE foam - 10mm concrete - 30mm PUR - 40mm cement mortar - 15mm granite paving *Inner surface*	R-Value: 3.00 m^2K/W U-Value: 0.33 W/m^2K

As can be observed, it is difficult to improve these thermal transmittances without extensive works and investment. The low energy demand reduction that could be achieved would be very expensive. Moreover, the necessary works would entail the temporary closure of the City Hall with the additional problem of relocating the workers, their equipment and computer to other municipal buildings.

Openings

The same concerns, described in the opaque envelope, can be extrapolated to openings. The existing fenestrations and glazing present satisfactory conditions and, for this reason, cannot be replaced.

Other strategies

The building has three lifts; one of them is actually a service lift that connects the ground floor with the mezzanine of the first floor. The consumption of these elevators has not been measured.

2.3.3. Energy Systems

Lighting system

As previously presented the actual lighting system is mainly constituted by fluorescent linear T8 lamps and fluorescent compact TCs of 4 pins. These ones will be replaced by LED technology.

TABLE 35: LAMPS THAT WILL BE REPLACED

Current				Proposed			
Type of light	Power (W)	Number	Total Power (W)	Type of light	Power (W)	Number	Total Power (W)
Fluorescent Compact TC	2x36	221	15912	LED Compact Fluorescent	2x20	221	8840
Fluorescent Linear T8	1x36	31	1116	LED Linear T8	1x20	31	620
Fluorescent Linear T8	1x58	37	2146	LED Linear T8	1x31	37	1147
Fluorescent Linear T8	2x58	4	464	LED Linear T8	2x31	4	248
Fluorescent Compact TC	2x9	191	3438	LED Compact Fluorescent	1x10	191	1910
Total		**484**	**23076**	**Total**		**484**	**12765**

TABLE 36: TOTAL POWER INSTALLED

	Current lighting system (W)	Renovation scheme (W)
Total power	25,186	14,875
Reduction	---	41%

This measure is assessed by means of energy Plus and the following results are obtained:

TABLE 37: EFFECT OF THE RENOVATION OF THE LIGHTING SYSTEM

	Baseline	Renovation scheme
Lighting consumption (MWh/year)	84.76	39.14
Savings (kWh/year)	---	45.62
Savings (%)	---	53.8%

HVAC system

Heating system

Efficiency of the heating system will be improved by means of a high Coefficient of Performance (COP) condensing boiler (current one is non-condensing). Moreover, the existing boiler is supplying domestic hot water to two buildings. As this situation is going to change (Kapitain Etxea will have an independent heating system), the total power is currently oversized leading to a reduction in the efficiency of the current equipment.

The new boiler has a COP of 1.1 and a total power of 130 kW.

At this point it is important to consider in the simulation the effect of the lamps replacement included in the previous point. Fluorescent lamps produce more heat than LED ones. This fact has an important effect in the thermal behaviour of the building and therefore in the heating consumption. This effect is observed in TABLE 38.

TABLE 38: ANNUAL ENERGY CONSUMPTION AFTER THE INTERVENTION IN THE LIGHTING SYSTEM

	Energy [MWh]	
System	Baseline	LED intervention
Room electricity	45.58	45.58
Lighting	84.76	39.14
Ventilation	13.26	13.26
Heating (gas)	131.63	170.96
Cooling	3.93	0.47

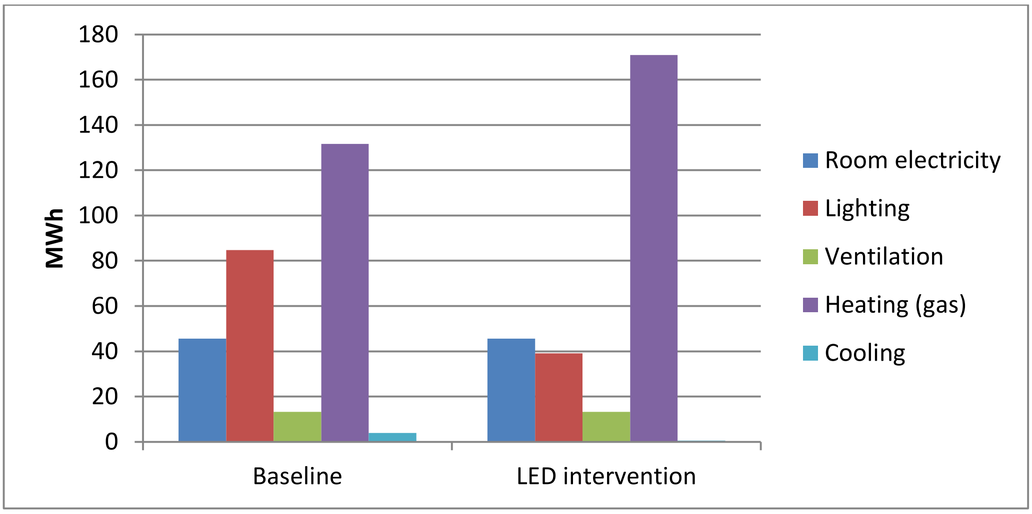


FIGURE 54: COMPARISON BETWEEN THE ENERGY CONSUMPTION OF THE BASELINE AND THE INTERVENTION IN THE LIGHTING SYSTEM

The heating consumption is increased almost a 30% due to the effect of this measure. This effect must be considered in the evaluation of the gas consumption of the new gas boiler. If only the replacement of the boiler is assumed the result obtained would be inaccurate.

TABLE 39: ANNUAL ENERGY CONSUMPTION AFTER THE REPLACEMENT OF THE GAS BOILER (RETROFITTING OF THE LIGHTING SYSTEM IS NOT CONSIDERED)

	Energy [MWh]	
System	Baseline	Boiler replacement
Room electricity	45.58	45.58
Lighting	84.76	84.76
Ventilation	13.26	13.26
Heating (gas)	131.63	105.31
Cooling	3.93	3.93

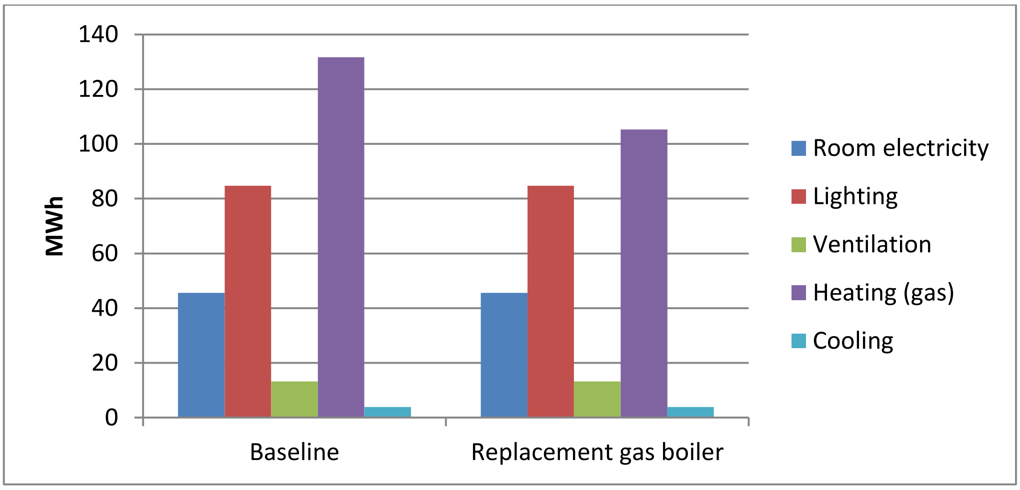


FIGURE 55: COMPARISON BETWEEN THE ENERGY CONSUMPTION OF THE BASELINE AND THE INTERVENTION IN THE GAS BOILER (RETROFITTING OF THE LIGHTING SYSTEM IS NOT CONSIDERED)

The final evaluation must consider these facts.

TABLE 40: ANNUAL ENERGY CONSUMPTION AFTER THE REPLACEMENT OF THE GAS BOILER PLUS THE INTERVENTION IN THE LIGHTING SYSTEM

	Energy [MWh]	
System	Baseline	Boiler replacement + LED intervention
Room electricity	45.58	45.58
Lighting	84.76	39.14
Ventilation	13.26	13.26
Heating (gas)	131.63	127.04
Cooling	3.93	1.56

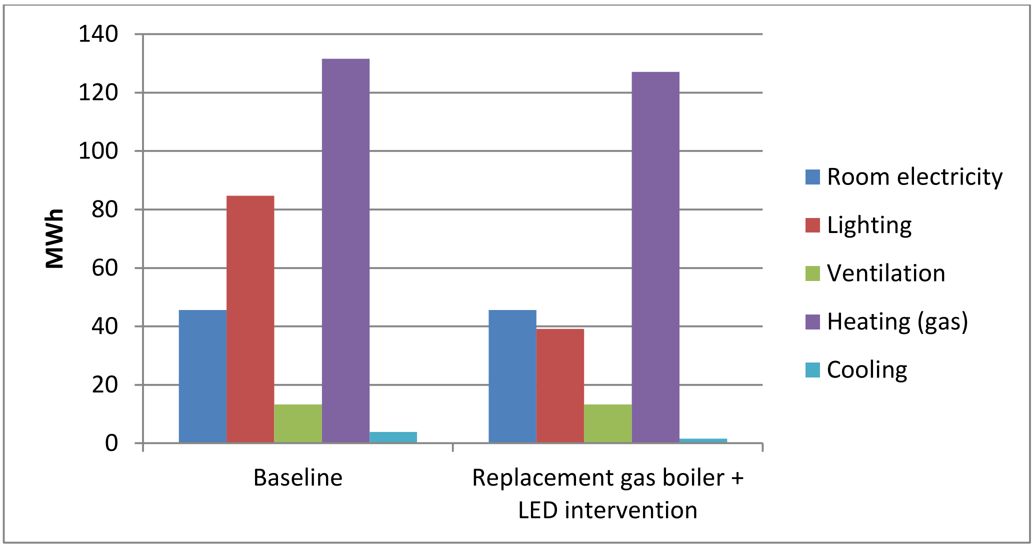


FIGURE 56: COMPARISON BETWEEN THE ENERGY CONSUMPTION OF THE BASELINE AND THE INTERVENTION IN THE GAS BOILER PLUS THE RETROFITTING OF THE LIGHTING SYSTEM

Apparently, the gas consumption is only reduced by 5 MWh per year. But it is necessary to underline that the consumption after the intervention in the lighting system would increase a 30%. For this reason, the actual reduction will be 25% of the estimated consumption of the heating system with the current gas boiler.

Cooling system

It has been stated in point 2 that the equipment related to the cooling system presents satisfactory efficiency characteristics. Moreover, a portion of this equipment has been recently installed. For this reason, the replacement of any device of the cooling system is not applicable.

Specifically, the Energy Efficiency Ratios (EER) values of the condenser units could be slightly improved. However, the investment for achieving this modest improvement is excessive and should not be considered.

2.3.4. Renewable energy sources

PV Panels

The renovation scheme includes the installation of Photo Voltaic (PV) panels on the roof. Once more, the problem related to space is a serious drawback. The total power installed will be limited by this fact.

The panels can be installed on the slopes of the roof, as observed in FIGURE 57. For this reason, they will be oriented in the direction of the roof gables. Thus, the azimuths for the panels are 60 and -25ª respectively. In addition, the will have the same slope as the gables have: 18º.

The total area for the panels is:

- Gables in Southeast: 209 m^2 ≈ 330 panels
- Gables in Southwest: 123 m^2 ≈ 190 panels

For the simulation a standard monocrystalline panel type has been selected. Its features are:

- Dimensions: 1,25 x 0,50 m
- Nominal Power: 121 Wp/m^2(75.6 Wp per panel)
- Tilt: 18º
- Generator PV Array Efficiency: 10.9% (annual average)
- Inverter DC to AC Efficiency: 95%

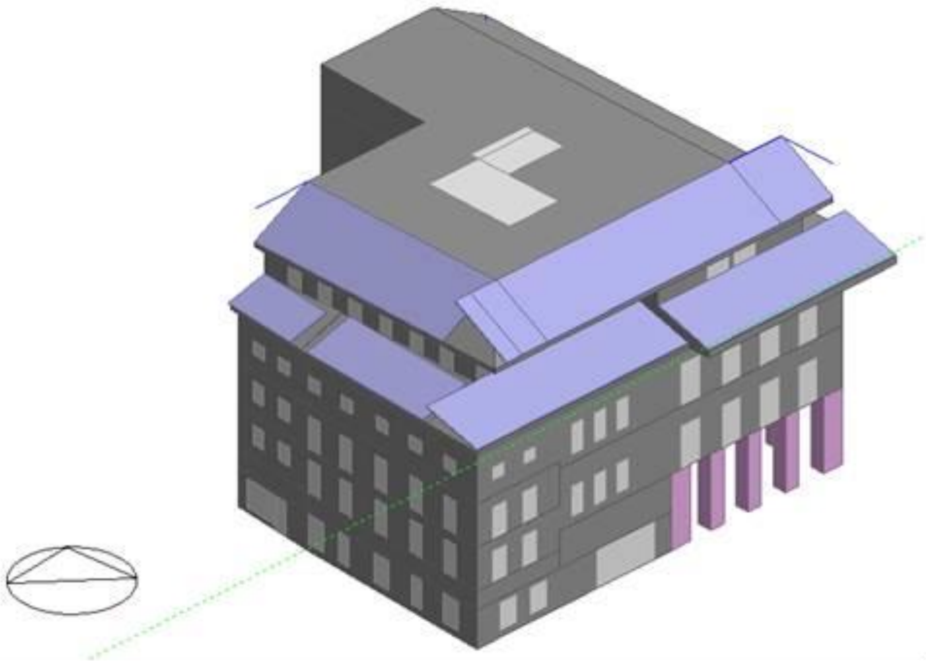


FIGURE 57: BASIC REPRESENTATION OF THE POSITION OF THE PV PANELS IN THE BUILDING

According to the simulation done by Energy Plus, and considering the effect of the shadings, this device will generate the following amount of electricity: 38,757 kWh per year.

TABLE 41: PV GENERATION PER MONTH

Month	Thermal Energy
January	1677
February	2228
March	3671
April	3800
May	4211
June	4410
July	4580
August	4190
September	3760
October	2856
November	1760
December	1614
TOTAL	38757

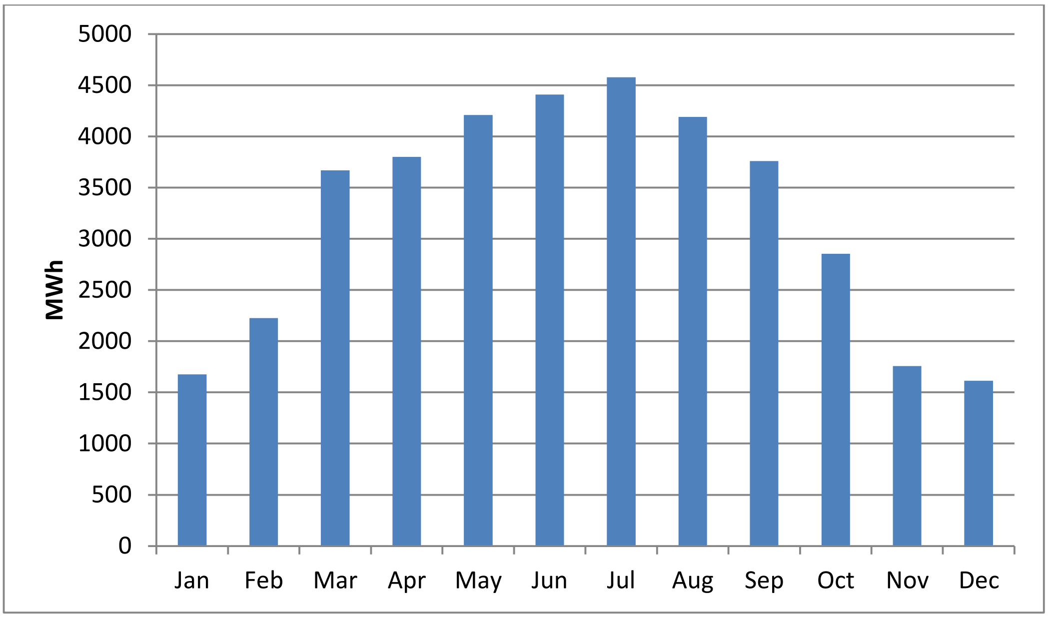


FIGURE 58: PV GENERATION PER MONTH

2.3.5. TOTAL IMPACT OF THE RENOVATION SCHEME

The selected renovation scheme is formed by the following measures:

- Replacement of the lighting system by LED technology; with a total power of 12,765 W (484 lights);
- Improvement of the heating system by replacing the current boiler by a condensing boiler, with a total power of 130 kW and a COP of 1.1;
- Installation of 40.2 kWp of PV panels for electricity generation on roof (332 m^2).

TABLE 42: SAVINGS AND NET ENERGY CONSUMPTION

	Baseline – Energy Plus Simulation [kWh]	Final Renovation Scheme [kWh]	Savings [kWh]
Room electricity	45,580	45,580	0
Lighting	84,760	39,140	45,620
Ventilation	13,260	13,260	0
Heating (gas)	131,630	127,040	4,590*
Cooling	3,930	1,560	2,370
TOTAL	279,160	226,580	52,580
Generation	0	38,757	38,757
TOTAL NET CONSUMPTION	279,160	187,823	91,337 (32%)

*Net balance, but not real saving

These values must be interpreted from another point of view. It is true that only 4,590 kWh in gas are saved if we compare the results of the renovation scheme and those obtained in the baseline. However, the gas consumption of the current gas boiler would increase if we do not reply it due to the intervention on the lighting system: 170,960 kWh. For this reason it could be stated that the saving obtained by the replacement of the gas boiler are 43,920 kWh. Hence, the total savings would be 130,667 kWh, a reduction of 46%.

TABLE 43 shows the comparison between final, primary energy and CO_2 emissions in the base scenario and the renovation option.

TABLE 43: FINAL ENERGY, PRIMARY ENERGY AND CO_2 EMISSIONS

		Final energy [kWh]	Primary energy [kWh]	CO_2 Emissions [kg CO_2 /kWh]
Baseline	Gas	131,630	132.946	26,853
	Electricity	147,530	385.053	95.747
	TOTAL		**517.999**	**122,599**
Renovation	Gas	127,040	128.310	25.916
	Electricity	60,783	158,644	39,448
	TOTAL		**286.954**	**65.364**
Savings			**231.045**	**57,364**
			44.6%	**46.7%**

As it can be seen in TABLE 44, approximately the 39% of energy is supplied by renewable energy systems.

TABLE 44: RENEWABLE SHARE

	Final Electricity Consumption [kWh]	Energy Generation [kWh]	Energy Generation [%]
PV generation	99,540	38,757	38.9%

2.4. ECONOMIC EVALUATION OF THE PROPOSED RENOVATION SCHEME

The costs of the selected renovation options were determined by consulting catalogues and installers. Costs comprise installation and equipment.

TABLE 45 presents the considered costs for the following renovation options:

- Replacement of the lighting system by LED technology;
- Improvement of the heating system by replacing the current boiler by a condensing boiler.
- Installation of PV panels for electricity generation on roof

TABLE 45: COSTS OF THE SELECTED RENOVATION OPTIONS

Renovation option	Price €
Condensing gas boiler	9761
Lighting system	10493
PV panels	149430
TOTAL	**169684**

The following table presents the economic parameters of the total of the renovation scheme, which has an estimated payback period of 5.6 years.

TABLE 46: ECONOMIC PARAMETERS OF THE RENOVATION

Energy savings	86,747 KWh
Energy price	0.14 €/kWh
Gas savings	4,590 kWh
Gas price	0.05 €/kWh
Costs renovation	169684 €
Savings	12374 €/year
Payback	5.6 years

3. *LEKUONA*

3.1. Building General Description

3.1.1. Location

The "Lekuona" building was a former bakery and, at present, it is owned by the Municipality of Errenteria in the Basque Country, Spain. The building, erected in the 1970s is currently abandoned. The central structure is formed by a large space with two adjacent buildings for a total area of 2018 m^2.

FIGURE 59: FRONT FAÇADE OF THE LEKUONA BUILDING

The Lekuona building is located next to the Oiartzun estuary, which affronts the building at the South. TABLE 47 presents the main location data of the building and FIGURE 60 and FIGURE 61 present the location in the city map and aerial view.

TABLE 47: LOCATION DATA OF THE BUILDING

Address	Lekuona, Urantzu Kalea 6, 20100 Errenteria, Gipuzkoa, Spain
Coordinates	43° 18' 51.57" N 1° 53' 55.59" W
Google Maps	https://www.google.es/maps/place/Renter%C3%ADa,+Guip%C3%BAzcoa/@43.3140981,-1.9007105,420m/data=!3m1!1e3!4m2!3m1!1s0xd51a8a8760df4ff:0xa183ca8bf4ada3b8

The Municipality plans to conserve and adaptively reuse the building due to its historic and aesthetic values, importance to the community and location. The Lekuona building represents the industrial activity of the area, which was the main economic force of the town. Moreover, it is partially protected by the Coastal Law due to its proximity to the estuary and Bay of Biscay. The industrial aspects of the building should therefore be preserved. In this way, the Municipality is carrying out an ambitious project to transform this abandoned building into a dance school and cultural centre. It will be known as "*Dantzagune – Arteleku*".The idea was to keep the original form of the building. However, when the municipality proceed to clean the contaminated soil on site (mandatory by law), the main building showed severe structural deficiencies. A further study revealed that portions of the structure were beyond economic viability. Therefore, the municipality decided to carry out an extensive renovation of the building. Some elements, especially those protected by the Coastal Law, will be preserved while others will be rebuilt and the building will be enlarged to accommodate this new use.

FIGURE 60: LOCATION IN THE CITY (MAP)

FIGURE 61: LOCATION IN THE CITY (AERIAL VIEW)

3.1.2. Shape and Orientation

FIGURE 62 presents the plan view and FIGURE 63 the proximity of the building to the estuary. The building has three floors and a basement. The ground floor and first floor have similar shapes, but the second floor is a later extension of the building. The building has a rectangular shape with an adjacent trapezoid. The building is oriented with an axis of almost 130º, with the main façade oriented to Southwest in parallel with the Oiartzun estuary.

FIGURE 62: LEKUONA RENOVATION PROJECT, PLAIN VIEW

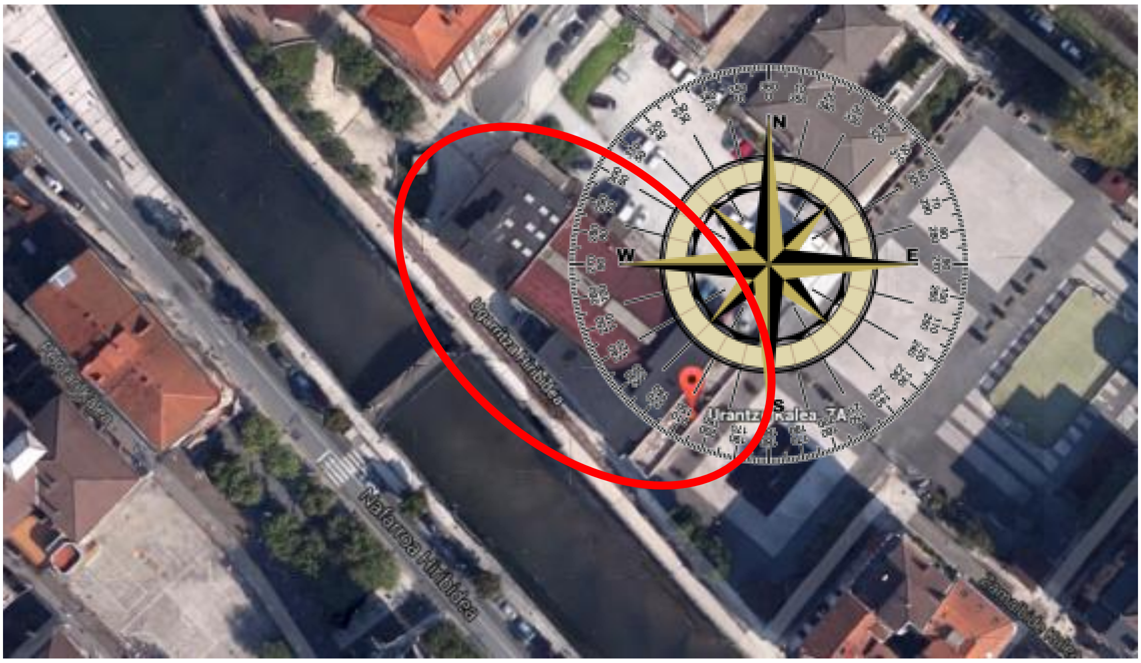
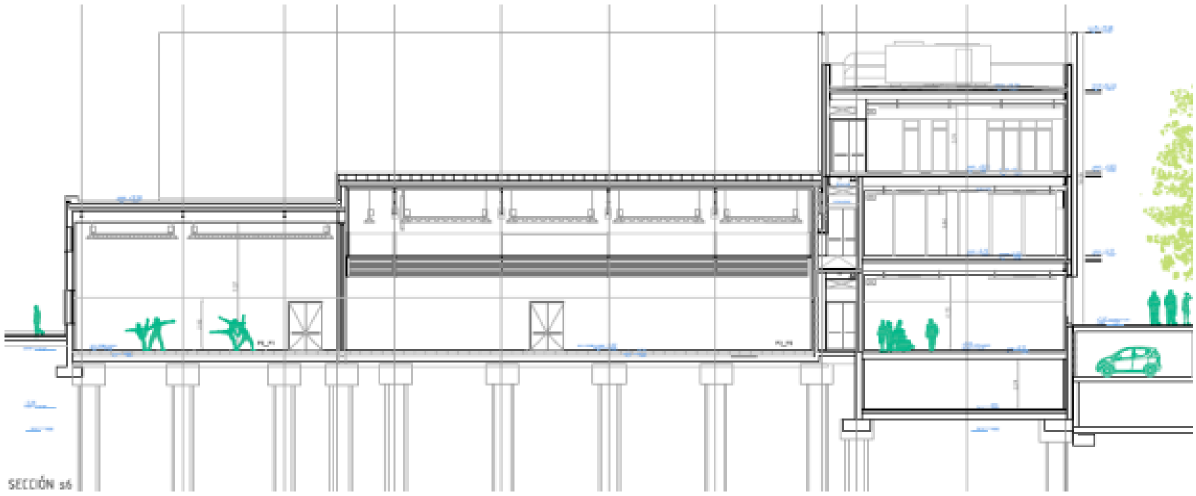


FIGURE 63: AERIAL VIEWFIGURE 5

FIGURE 64 presents two different cross sections of the renovation project.



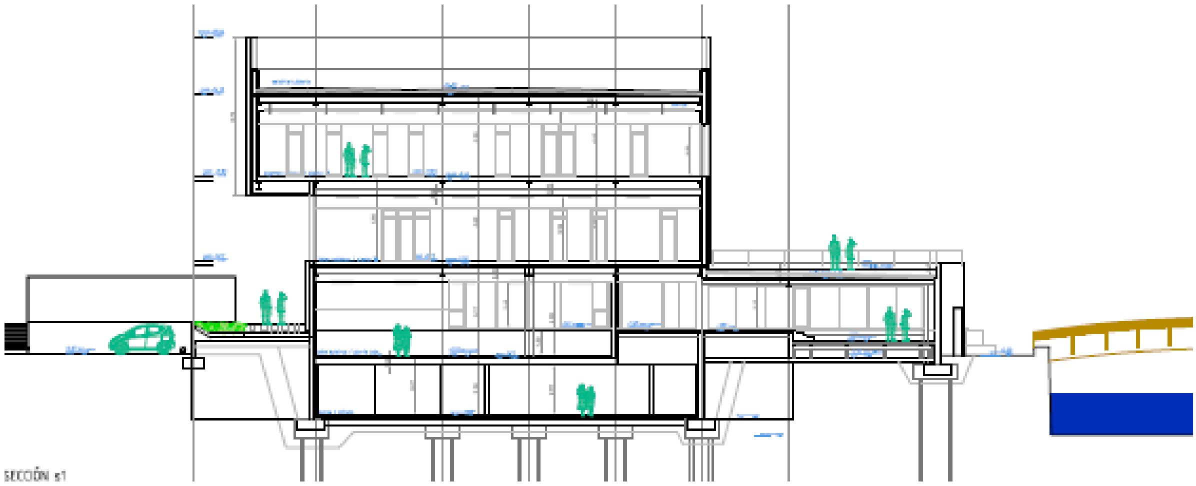


FIGURE 64: DIFFERENT CROSS SECTIONS OF THE RENOVATION PROJECT

3.1.3. AREA AND VOLUME

The original building has a total area of 2018 m^2. However, the renovated building will have a larger total area (in fact, the building will have an added floor) of 4406 m^2 (3687 m^2 of useful area). The final volume will be 20328 m^3.

TABLE 48: USEFUL SURFACE AND VOLUME PER FLOOR

Floor	Constructed Surface	Useful Surface	Volume
Basement	908	799	3177
Ground Floor	1682	1490	7452
First	1006	783	6185
Second	745	576	3347
Third (technical room)	65	39	167
TOTAL	4406	3687	20328

3.1.4. CURRENT USE

The Lekuona was abandoned for many years and currently there are plans underway to rehabilitate it. The renovation project, which was done in line with energy efficiency standards, has been approved and the project has already started. The design has been developed in order to qualify the building with the mark A according to the requirements of the Technical Building Code of Spain (CTE).

The new use of the building will entail an inevitable increase in energy demand (currently there is no energy consumption). For this reason, the municipality has commissioned the design of the building with minimum energy demand and with the inclusion of Renewable Energy Sources (RES).

3.2. CURRENT BUILDING CONDITIONS

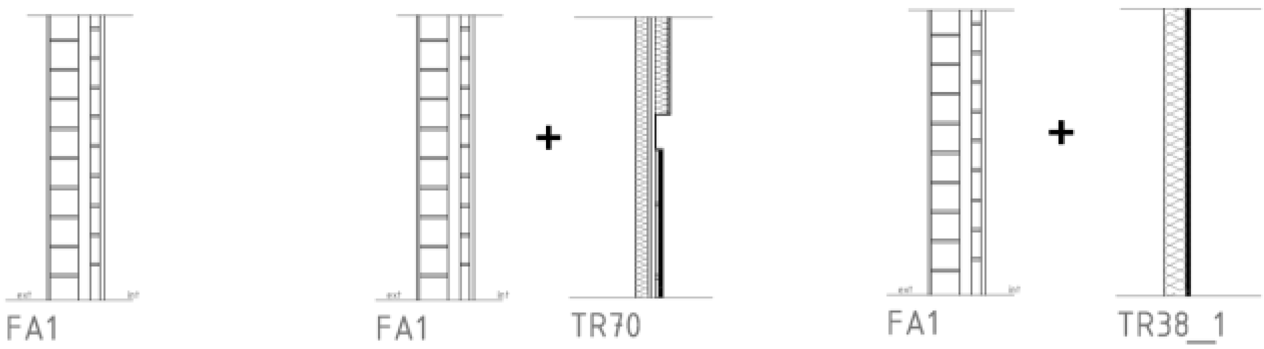
3.2.1. CONSTRUCTIVE BUILDING CHARACTERISTICS:

Envelope Elements

The new constructive typologies of the envelope elements are in compliance with the aim of nZEB buildings. As these elements have already been well designed for the new, it is not possible to reduce the energy demand by altering their composition or typology.

Walls

The external walls can be divided in two main groups: the original walls that must be preserved and the new walls. The preserved walls were constructed of two layers of masonry with an air gap and no insulation. They will be insulated internally by means of mineral wool and plasterboards (FIGURE 65). This will retain their aesthetic appearance, according to the requirements of the Coastal Law yet provide better insulation performance. The new walls will be new masonry with a similar insulation treatment. As these walls are new they will perform much better for the aim of nZEB.



- Double masonry leaf with air gap

- Double masonry with air gap
- Mineral wool 50mm
- Plasterboard
- Mineral wool 50mm
- Plasterboard

- Double masonry with air gap
- Mineral wool 80mm
- Plasterboard

FIGURE 65: CONSTRUCTIVE COMPONENT OF THE ORIGINAL BUILDING (LEFT) AND TWO RENOVATION SOLUTIONS FOR WALLS

Roof

The roof is also divided in two main groups: the existing and the new. The existing roof, made of reinforced concrete will be augmented by corrugated sandwich panels of high density mineral wool. The new roof will have a non-accessible flat roof insulated with extruded polystyrene (XPS) panels. The existing roofs do not have the same historic values as the walls as they are not seen so it is possible to greatly improve the insulation performance.

Ground Floor

The basement floor is formed by a concrete finish over the structural concrete slab-on-ground; therefore, there is no insulation. The floor is in direct contact with the soil and therefore has very poor thermal properties. As the original use of the building was industrial this was acceptable, however now the use is changing this performance must be improved. Therefore in the main room to be used a wood structure will be created over the concrete slab with insulation. This will provide a more suitable floor as well as improve the thermal properties.

These typologies are more shown graphically in TABLE 49, TABLE 50 and TABLE 51.

TABLE 49: DIFFERENT EXISTING TYPOLOGIES FOR WALLS

Part of envelope	Typology	Characteristics
Previous wall of the existing building	*Outer surface* - 12mm mortar render - 120mm masonry - 35mm air gap - 25mm masonry *Inner surface*	R-Value: 0.76 m^2K/W U-Value: 1.31 W/m^2K
Retrofitted wall of the existing building	*Outer surface* - 12mm mortar render - 120mm masonry - 35mm air gap - 25mm masonry - 80mm mineral wool - 13mm plasterboard *Inner surface*	R-Value: 2.87 m^2K/W U-Value: 0.35 W/m^2K
Retrofitted wall of the existing building (main room)	*Outer surface* - 12mm mortar render - 120mm masonry - 35mm air gap - 25mm masonry - 13mm plasterboard - 50mm mineral wool - 30mm plasterboard - 50mm mineral wool - 13mm plasterboard *Inner surface*	R-Value: 3.56 m^2K/W U-Value: 0.28 W/m^2K
Wall of the extension building	*Outer surface* - 3mm aluminium clad. - 150mm air gap - 100mm EPS	R-Value: 6.36 m^2K/W U-Value: 0.16 W/m^2K

	- 200mm concrete block - 50mm mineral wool - 13mm plasterboard - 50mm mineral wool - 13mm plasterboard *Inner surface*	

TABLE 50: DIFFERENT EXISTING TYPOLOGIES FOR ROOFS

Part of envelope	Typology	Characteristics
Retrofitted roof of the existing building	*Outer surface* - 100mm sandwich panel – mineral wool - 150mm air gap - 80mm mineral wool - 60mm plaster - 50mm mineral wool *Inner surface*	R-Value: 6.61 m^2K/W U-Value: 0.15 W/m^2K
Roof of the extension building	*Outer surface* - 60mm gravel - 80mm XPS - 120mm concrete - 150mm air gap - 80mm mineral wool - 40mm plaster - 50mm mineral wool - 10mm plasterboard *Inner surface*	R-Value: 7.09 m^2K/W U-Value: 0.14 W/m^2K

TABLE 51: DIFFERENT EXISTING TYPOLOGIES FOR GROUND FLOOR PAVING

Part of envelope	Typology	Characteristics
Ground floor paving	*Outer surface* - 20mm ceramic pave - 300mm concrete slab *Inner surface*	R-Value: 2.04 m^2K/W U-Value: 0.49 W/m^2K
Ground floor paving (main room)	*Outer surface* - 80mm wood board - 120mm air gap - 80mm cement mortar - 40mm mineral wool - 300mm concrete slab *Inner surface*	R-Value: 4.26 m^2K/W U-Value: 0.24 W/m^2K

Windows and Doors

All the windows and doors will be replaced. They are of varying dimensions but all have similar aluminium frames and single-pane glazing; all very poor in terms of thermal performance. They do not have any specific historic or aesthetic value as the structure was altered over time. These windows will be replaced with three types all with double-glazing with an air gap. Two different types of windows and doors will be used for the existing openings that will respect the industrial origins of the building. A new type of window will be introduced for the curtain walls of the new structure:

- Window type 1: 44.1BE / 16 / 33.1
- Window type 2: 6 BE / 16 / 4+4
- Curtain wall: 8 toughened BE / 16 / 44.1

TABLE 52: DIFFERENT EXISTING TYPOLOGIES FOR GLAZING

Skylight type	Typology	Characteristics
Window type 1	*Outer surface* - 44.1BE - 16 air gap - 33.1 *Inner surface*	U-Value (ISO 15099/NFRC): 2.60 W/m²K
Window type 2	*Outer surface* - 6BE - 16 air gap - 4+4 *Inner surface*	U-Value (ISO 15099/NFRC): 3.04 W/m²K
Curtain wall	*Outer surface* - 8 toughened BE - 16 air gap - 44.1 *Inner surface*	U-Value (ISO 15099/NFRC): 2.62 W/m²K

Airflows and Pathologies

The building improvements have been designed with energy efficient suitable materials; with an approved construction process therefore no relevant airflows are expected. External doors will be programmed to open and close automatically.

3.2.2. Energy Systems

HVAC

The new Heating Ventilation and Air Conditioning (HVAC) system of the building will be centralized and use water-to-air Air Handling Units (AHUs). These elements will gather all the HVAC functions together: ventilation, heating and cooling. Various AHUs will be installed strategically on the roof to properly distribute the conditioned air to the assigned rooms or areas. The energy supply will be done by four pipes, two for heating and two for cooling.

The Domestic Hot Water (DHW) necessary to supply the heating part of the system will be provided by a pellet biomass boiler placed in the basement. This boiler has a nominal power of 201 kW and is complemented with an expansion tank and two buffer tanks of 1000l. The production of cold water for the AHUs will be done by an air-to-water chiller with a nominal power of 271 kW and an EER of 2.75.

The air distribution will be done through a system of galvanized steel air ducts with long throw jet nozzles, multi-jet nozzles and diffusors.

The mechanical ventilation flow provided by the AHUs, will be 12.5 l/s (air quality IDA-2) for all the rooms and 3.8 l/s for the main room

Lighting

As with the other systems, lighting has been designed according to the Spanish and European Normal standards CTE – DB HE and UNE – EN 12464.1 The former establishes the expression to determine the value for the energy performance of the system (*Valor de Eficiencia Energética de la Instalación* in Spanish, VEEI) and the maximum values that are acceptable or the design concept according to building use. The latter determines the average illuminance at the working plane (E_m) according to the use of the building. For an educational building the VEEI is 3.5 W/m^2·100 luX and the E_m is 300 lux. This means that the installed power per area should be 10.5 W/m^2.

ICT

Currently it is not thoroughly defined the amount of computers and printers in the building, therefore statistical values are considered.

Others

The building will have two lifts.

3.2.3. ENERGY CONSUMPTION & ENERGY GENERATION

Electricity

Currently, as the building is not in use, there is no electricity consumption. In the estimation done by the engineering company responsible for the designed the building, the anticipated electricity consumption will be 173,456 kWh/year.

Gas

There will be no natural gas consumption in the building. A system was considered but this was later rejected.

RES (Renewable Energy System)

The heating system will be supplied by a biomass fired boiler. This technique is considered renewable. As mentioned previously, the heating system will be fed by a pellet-fired boiler to provide nominal power of 201 kW.

As there is no real data on consumption yet, the engineering company has estimated it to be: 158,823 kWh/year.

Others

It is not anticipated there will be additional energy consumption in Lekuona building.

Final Energy Consumption and CO_2 Emissions

As it has been previously mentioned, the Lekuona building is currently being renovated and it is not possible to work from the basis of actual data on real energy consumption. For purposes of the CERtuS project the calculation provided by the engineering company will be used.

TABLE 53: ENERGY PARAMETERS FOR A YEAR

	Final Energy kWh	Energy Dens. kWh/m2	Primary Energy kWh	CO_2 Emissions kg CO_2
Total	332,279	82.3	611,543	111,012

3.3. Renovation Scheme

3.3.1. Aim of the renovation plan

The Municipality of Errenteria has undertaken an enormous effort to rehabilitate a building that was abandoned for many years. The policy of the local government is clearly focused on an energy efficient solution. Hence, this renovation project will be a reference benchmark for the region. In fact, the building is labelled as Energy Category A, a high standard, according to section 2.2.2 of the HE0 of the DB-HE, a part of the mandatory Spanish Technical Building Code (CTE in Spanish). This means that the building has been designed to present very low energy consumption and CO_2 emissions compared to a standard building. Therefore, the building has been carefully designed to achieve this important milestone. Suitable envelope typologies and materials, use of RES or efficient systems were considered from the beginning of the project.

The aim of CERtuS project is to achieve an average primary energy reduction between 75% and 80% of the current demand and to ensure that between 50% and 90% of the consumed energy is generated by renewable energy sources installed in the building.

Part of the former building is protected by the Spanish Coastal Law. This must be considered for the eventual implementation of new Renewable Energy Sources, such us thermal solar or PV panels.

3.3.2. Energy demand Reduction

Since the building is being renovated and some historic elements will be retained the possibilities to reduce the energy demand are seriously restricted. Nevertheless, the building has been designed so demand reductions are minimized; moreover, renovation works have already started. There has been a very good balance between retaining elements of the existing building and meeting energy conservation parameters.

3.3.3. Energy systems

The same appraisal can be stated for the energy systems: lighting and HVAC. All the mandatory requirements have been considered and efficient equipment has been selected. The election of the HVAC system was done according the building features and distribution keeping in mind the need for energy efficiency as well as comfort for the users.

3.3.4. Renewable Energy Sources

Biomass boiler

The heating requirements of Lekuona, according to the renovation project are summarized in the following table.

TABLE 54: ITEMISED HEATING REQUIREMENTS FOR LEKUONA

AHU area	Power per area [W/m²]	Total power [W]
Changing rooms	7.4	8907
Vault (Polyvalent room 1)	208.9	98260
Cube (Polyvalent room 2)	212.8	55829
East	59.7	41361
North	80.2	23609
Corridors	69.9	30883
South (Ground Floor)	221.6	61612
South (First Floor)	101.4	14943
	TOTAL	**335407**

In order to define the biomass boilers capacity, these requirements are gathered in two “groups” that would work simultaneously: multipurpose rooms and the rest of the building.

TABLE 55: SUMMARISED HEATING REQUIREMENTS FOR LEKUONA

AHU area	Total power [W]
Multipurpose rooms	154089
Rest of the building	181318
TOTAL	**335407**

Considering that approximately 50% of the building will be used at any given time a power of 168 kW is necessary. Hence, a pellet-fired biomass boiler of 201 kW of nominal power was selected. This equipment presents the following characteristics:

- Nominal power: 201 kW
- Power range: 55-201 kW
- Insulated boiler body
- Safety heat exchanger
- Suction system with speed regulation
- Automatic cleaning
- Two zone combustion chamber
- Automatic cleaning system

Biomass, despite being an energy source where combustion is required, is considered as a renewable energy source. Thus, all the energy consumption related to the heating system, 158,823 kWh/year, comes from a renewable source. The fuel for the biomass boiler can be wood chips and the process is very efficient. The CO_2 emitted is the same amount as is absorbed when the plants were growing. Therefore, biomass is classed as carbon-neutral renewable energy. As there are many bio byproducts in the region such as wood chips from manufacturing and logging this was an intelligent decision.

Micro Combined Heating and Power (CHP) Alternative

There are other alternatives that were also considered.

1) Cogeneration of electricity with a micro CHP (Combined Heat and Power) with the biomass heater and
2) Cogeneration of heat and electricity with the installation of a small natural gas fired boiler

These were considered because the thermal loads related to a heating system can also be used to locally produce electricity by means of cogeneration. Such systems have greater efficiency as they do not incur energy losses due to transporting electricity over long distances.

Initially, it was decided to adapt the second cycle of the biomass boiler. However, due to the characteristics of the selected equipment, this idea was soon rejected.

The second alternative was then investigated - A micro-CHP gas-fired boiler that could be added in parallel to the heating system. In the simulation made in the Energy Plus programme this idea was been further defined and analysed. The micro-CHP equipment is a model of SenerTec DACH with a thermal power of 12.5 kW and an electric power of 5.5 kW. The cycle must be accompanied by a water storage tank of 3m^3. This important fact has to be considered to ensure if there is available space in the boiler room of the building. This micro-CHP generates a relevant amount of electric power. In FIGURE 66, this generation is represented by means of a monthly evolution graph.

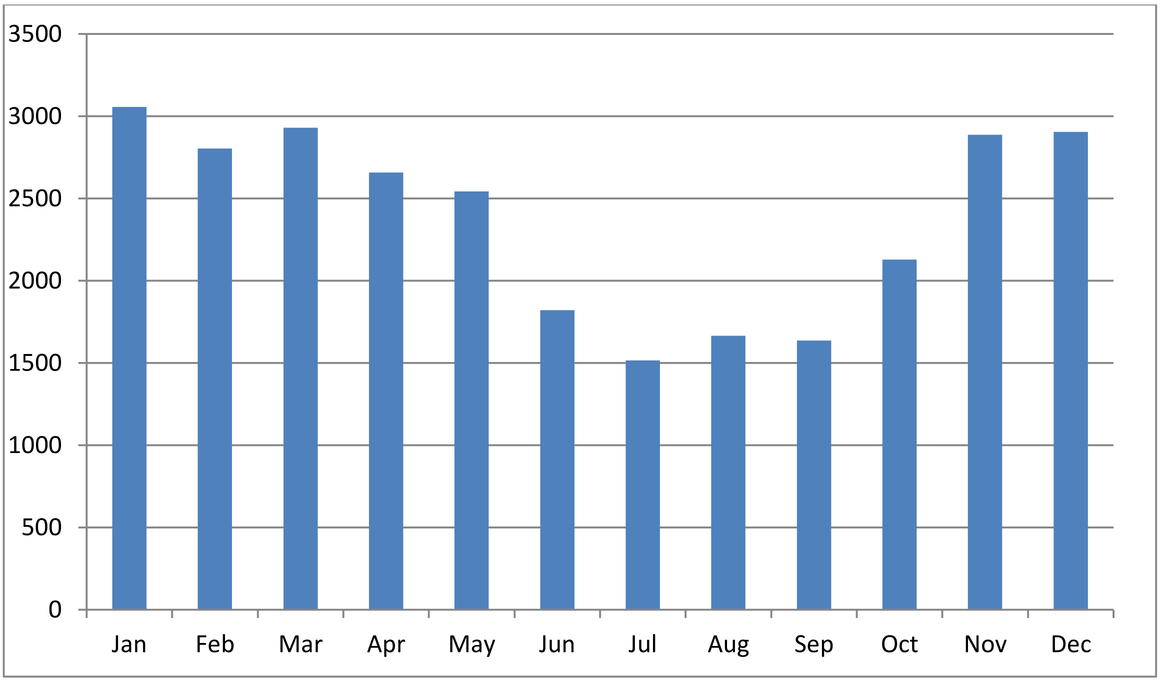


FIGURE 66: ENERGY GENERATED BY THE MICRO-CHP [KWH]

Nevertheless, this electric generation design means there will be an inherent consumption of natural gas in the micro-CHP. Therefore, the consumption of biomass (a renewable source) for heating purposes will be reduced while the use of natural gas (a non-renewable resource) is increased. The detailed consumption and generation associated to the biomass boiler and the gas-fired micro CHP is displayed in TABLE 56. Both in

FIGURE 66 and TABLE 56 can be observed how the power generation is reduced in summer, this is because the heating system will not be used.

TABLE 56: MONTHLY CONSUMPTION AND GENERATION OF THE BIOMASS BOILER AND THE DEFINED MICRO-CHP

Month	Biomass consumption [kWh/year]	Gas consumption [kWh/year]	Electricity generation [kWh/year]
January	12,182	12,583	3,057
February	8,264	11,541	2,804
March	6,662	12,068	2,931
April	3,927	10,957	2,658
May	487	10,498	2,543
June	315	7,554	1,822
July	296	6,308	1,516
August	275	6,933	1,666
September	292	6,790	1,636
October	365	8,804	2,129
November	3,776	11,894	2,888
December	9,661	11,962	2,905
TOTAL	**46,506**	**117,898**	**28,561**

This data was analysed carefully because the amount of electrical power generated by the gas fired micro-CHP is relevant and will imply the consumption of gas contrary to the original nZEB goals. However, the use of natural gas in the micro CHP to generate electricity locally will reduce somewhat the need to use the biomass heater. For these reasons, the implementation of this measure presents an important change in the original nZEB goals.

Finally this idea was rejected and electricity will be supplied from the existing municipal source supplemented with photovoltaic panels installed on the roof.

Photovoltaic (PV) Panels

FIGURE 67 shows the different roof areas of the building. Area 1 and 2 are at the same level. They are differentiated due to the slight slope in area 2. In the project, area 3 is surrounded by a parapet wall which is actually an extension of the aluminium façade cladding. This can be observed in FIGURE 63. Therefore, the effectiveness of PV panels installed in this area would be seriously affected by the shadow cast by this parapet. Two different scenarios have been considered for the installation of PV panels, one considering the parapet and other ignoring it.

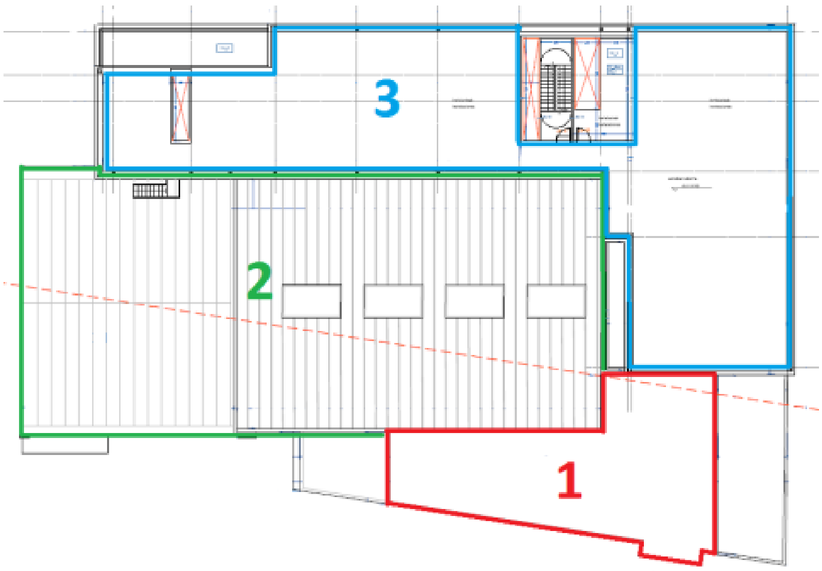


FIGURE 67: ROOF AREAS

Despite being an important topic it is necessary to consider the shading caused by the building element and orientation of the building. Energy Plus is a software tool that can estimate the production of electricity considering these factors (see FIGURE 68). Lekuona is not perfectly oriented to south but presents, an azimuth of 35º. Despite this, the PV panels should be installed keeping with the orientation of the building in order to minimize the visual impact and align with the architectural elements.

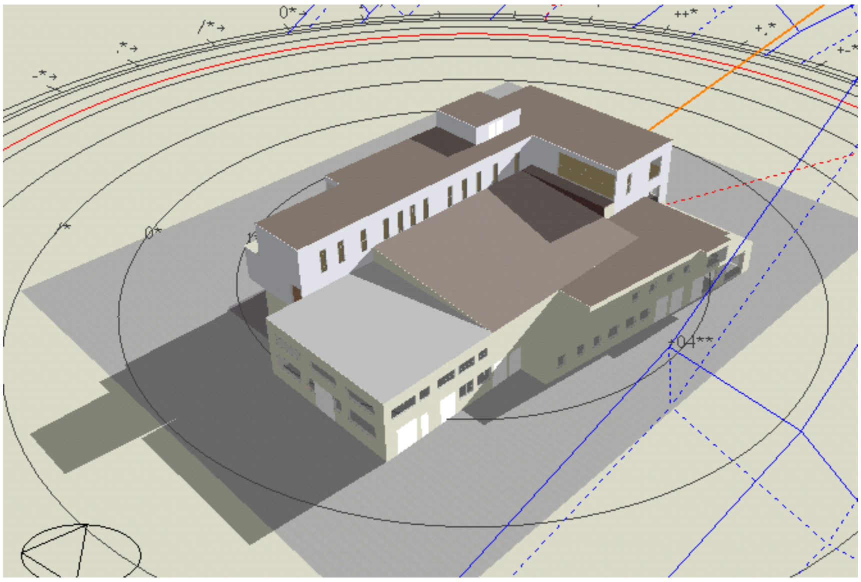


FIGURE 68: SHADINGS ON AREA 2. SIMULATION OF THE SOLAR INCIDENCE OF LUKUONA AT 09AM ON OCTOBER 15TH

For the simulation a standard monochristallyne panel type was selected. Its features are:

- Dimensions: 1.25 x 0.50 m
- Nominal Power: 121 Wp/m^2(75.6 Wp per panel)
- Tilt: 43º
- Generator PV Array Efficiency: 10.9% (annual average)

- Inverter DC to AC Efficiency: 95%

As has been commented, two scenarios were considered, and both have been simulated with Energy Plus:

- Scenario 1: install panels in areas 1 and 2. Total of 264 panels, i.e. 165 m^2 of solar surface.
- Scenario 2: install panels in areas 1, 2 and 3. Total of 450 panels, i.e. 281 m^2 of solar surface.

As can be seen in TABLE 57 and FIGURE 69, scenario 1 ensures a generation of 21.06 MWh/year, with a specific production of 1054 kWh/kWp/year, while scenario 2 ensures a generation of 35.75 MWh/year, with a specific production of 1050 kWh/kWp/year TABLE 57 presents the variation of production during the whole year.

TABLE 57: MONTHLY SIMULATION RESULTS IN SCENARIO 1 AND SCENARIO 2

Month	SCENARIO 1	SCENARIO 2
	Electricity generation [kWh/year]	Electricity generation [kWh/year]
January	1,068	1,813
February	1,218	2,068
March	1,800	3,055
April	1,830	3,106
May	2,259	3,834
June	2,188	3,713
July	2,393	4,061
August	2,381	4,041
September	2,039	3,461
October	1,706	2,895
November	1,216	2,064
December	961	1,631
TOTAL	**21,064**	**35,745**

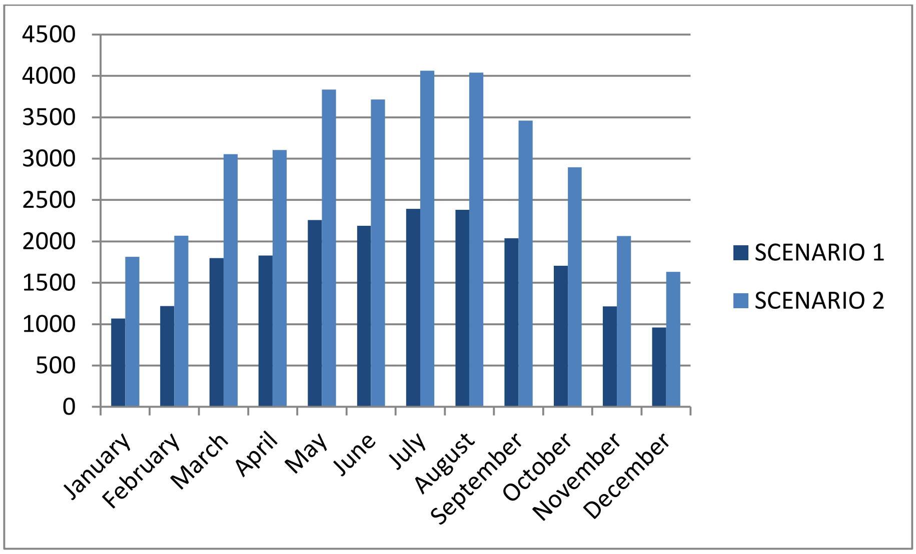


FIGURE 69: MONTHLY SIMULATION RESULTS IN SCENARIO 1 AND SCENARIO 2 [KWH/YEAR]

It must be emphised that the implementation of the scenario 2 implies the removal of the parapet that will be installed on the roof of the second floor.

3.3.5. Total impact of the renovation scheme

Because the use of the two alternatives for a Micro-CHP was rejected due to their disadvantages only two possibilities are considered at this point: the scenarios of using PV technology. In the assessment of the total impact the following scenario were considered:

- PV Scenario 1 (PVS1): 264 PV Panels + Biomass boiler
- PV Scenario 2 (PVS2): 450 panels + Biomass boiler

The following Table shows the achievable savings and net energy consumption of each scenario.

Table 58: Energy savings

Scenario	Savings	Net consumption	
	kWh	kWh	%
Baseline	0	332,279	
PVS1	21,064	311,215	93.6%
PVS2	35,745	296,534	89.2%

The combined use of PV panels and gas boiler ensures an important ratio of energy supply by Renewable Energy Sources.

Table 59: Energy supply

Scenario	Energy Consumption kWh	Renewable Energy Generation kWh	Ratio of Renewable Energy Generation %
PVS1 + biomass boiler	332,279	179,887	54.1%
PVS2 + biomass boiler	332,279	194,568	58.6%

The results were also assessed in terms of final energy, primary energy and CO_2 emissions considering the following conversion factors used in Spain:

- Electricity to primary energy – 2.61 kWh E.primaria /kWh electricity
- Natural gas to primary energy – 1.01 kWh E.primaria /kWh natural gas
- Biomass to primary energy – 1 kWh primary energy/kWh biomass
- Electricity to CO_2 emissions – 0.649 kg CO_2 /kWh electricity
- Natural gas to CO_2 emissions – 0.244 kg CO_2 /kWh natural gas
- Biomass to CO_2 emissions – 0 kg CO_2 /kWh biomass

Table 60: Energy parameters for a year

	Final Energy kWh	Primary Energy kWh	CO_2 Emissions kg CO_2
Baseline	332,279	611,543	112,573
PVS1 + biomass boiler	332,279	556,566	98,902
PVS2 + biomass boiler	332,279	518,249	89,374

3.4. ECONOMIC EVALUATION OF THE PROPOSED RENOVATION SCHEME

The costs of the selected renovation options were determined by consulting catalogues and installers.

TABLE 61 presents the considered costs for the proposed scenario:

- Scenario 2: installation of 450 panels, 281 m^2 of solar surface, 34.04 kWp

TABLE 61: COSTS OF THE RENOVATION OPTIONS

Renovation option	Price €
PVS2	126.588

The following table presents the economic parameters of the total of the renovation scheme, which has an estimated payback period of 25 years.

TABLE 62: ECONOMIC PARAMETERS OF THE RENOVATION

Energy savings	35,745 KWh
Energy price	0.14 €/kWh
Costs renovation	126588 €
Savings	5004 €/year
Payback	25 years

ANNEX A

The CO_2 emissions factors and the coefficient of transformation to Primary Energy of different final energy sources in Spain are published by IDAE and are currently under revision. In this document the version dated 03/03/2014 was used and is presented below[1].

Factores de conversión de energía final a primaria					
		Valores Propuestos			Valores actuales (Nota 1)
	Fuente	kWh E.primaria renovable /kWh E. final	kWh E.primaria no renovable /kWh E. final	kWh E.primaria /kWh E. final	kWh E.primaria /kWh E. final
Electricidad convencional Nacional	(*)			2,461	
Electricidad Nacional de origen 100% renovable	(**)	0,326	0		
Electricidad Nacional de origen 100% no renovable	(**)	0	2,135		
Electricidad convencional peninsular	(**)	0,341	2,082	2,423	2,61
Electricidad convencional extrapeninsular	(**)	0,073	3,052	3,125	3,35
Electricidad convencional Baleares	(**)	0,094	3,060	3,154	
Electricidad convencional Canarias	(**)	0,059	3,058	3,117	
Electricidad convencional Ceuta y Melilla	(**)	0,066	2,759	2,824	
Gasóleo calefacción	(***)	0,003	1,179	1,182	1,08
GLP	(***)	0,003	1,201	1,204	1,08
Gas natural	(***)	0,005	1,190	1,195	1,01
Carbón	(***)	0,002	1,082	1,084	1,00
Biomasa	(***)	1,003	0,034	1,037	
Biomasa densificada (pelets)	(***)	1,028	0,085	1,113	

(*) Valor obtenido de la Propuesta de Documento Reconocido: Valores aprobados en Comisión Permanente de Certificación Energética de Edificios de 27 de Junio de 2013.
(**) Según cálculo del apartado 5 de este documento.
(***)Basado en el informe "Well to tank Report, version 4.0" del Joint Research Intitute.
Nota 1: Valores utilizados actualmente en CALENER, CE3 y CEX según Documento reconocido "Escala de calificación energética para edificios existentes"

Factores de emisiones de CO2			
		Valores Propuestos	Valores actuales (Nota 1)
	Fuente	kg CO2 /kWh E. final	kg CO2 /kWh E. final
Electricidad convencional Nacional	(*)	0,399	
Electricidad Nacional de origen 100% renovable	(**)	0	
Electricidad Nacional de origen 100% no renovable	(**)	0,521	
Electricidad convencional peninsular	(**)	0,372	0,649
Electricidad convencional Extra peninsular	(**)	0,867	0,981
Electricidad convencional Baleares	(**)	0,960	
Electricidad convencional Canarias	(**)	0,811	
Electricidad convencional Ceuta y Melilla	(**)	0,732	
Gasóleo calefacción	(***)	0,311	0,287
GLP	(***)	0,254	0,244
Gas natural	(***)	0,252	0,204
Carbón	(***)	0,472	0,347
Biomasa	(***)	0,018	neutro
Biomasa densificada (pelets)	(***)	0,018	neutro

(*) Valor obtenido de la Propuesta de Documento Reconocido: Valores aprobados en Comisión Permanente de Certificación Energética de Edificios de 27 de Junio de 2013
(**) Según cálculo del apartado 5 de este documento.
(***)Basado en el informe "Well to tank Report, version 4.0" del Joint Research Intitute.
Nota 1: Valores utilizados actualmente en CALENER, CE3 y CEX según Documento reconocido "Escala de calificación energética para edificios existentes"

[1] http://www.minetur.gob.es/energia/desarrollo/EficienciaEnergetica/RITE/propuestas/Documents/2014_03_03_Factores_de_emision_CO2_y_Factores_de_paso_Efinal_Eprimaria_V.pdf

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