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 COIMBRA, PORTUGAL FULLY DOCUMENTED WITH TECHNICAL AND ECONOMIC EVALUATION

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Deliverable D2.1: Short Description
The document presents three renovation schemes for Coimbra, Portugal, 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This deliverable contains original unpublished work except where clearly indicated otherwise.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.

TABLE OF CONTENTS

List of Figures

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

Acronym	Definition
CFL	Compact Fluorescent Lamp
CHP	Combined Heat and Power
COP	Coefficient Of Performance
EER	Energy Efficiency Ratio
ESCO	Energy Service COmpany
HVAC	Heat Ventilator Air Conditioning
ICT	Information and Communications Technologies
LED	Light-Emitting Diode
nZEB	nearly Zero-Energy Building
PV	PhotoVoltaic
THC	systems of Temperature and Humidity Control

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 in four municipalities 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 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 Municipality of Coimbra, Portugal.

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:

- **Elementary School of Solum**: The building was built in the 1950s and until the 1970s this was an annex school to the teacher training colleges dedicated to pedagogical training. In the 1990s it was converted into an Elementary School. The construction of refectory and a partial renovation of the building was done 10 years ago.
- **Municipal House of Culture**: The building was built in 1991-1993 and opened on October, 26th 1993. The building is located near to the city centre and near to the University. It is used as Municipal House of Culture and has several cultural equipment, such as library, auditorium and art gallery, as well as several offices.
- **Coimbra Town Hall**: The building was built after the demolition of part of the old Monastery of Santa Cruz. The demolitions works and construction was carried out mainly between 1876 and 1879, but some construction works were developed gradually until the beginning of the 20th century. The building is used as the town hall of the Municipality of Coimbra, being mainly constituted by offices and storage areas.

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 selected renovation options are:

- **Elementary School of Solum**: Increase the PV system to 72 PV panels; Replacement of all T8 lamps with electromagnetic ballast by T5 lamps with electronic ballast; Replacement of the gas boiler by a heat pump.
- **Municipal House of Culture**: Installation of 770 PV panels; Replacement of all lamps by LEDs; Replacement of the THC and mono-split systems by systems with higher COP/EER.
- **Coimbra Town Hall**: Installation of 126.1 kWp of PV tiles; Replacement of all lamps by LEDs; Replacement of the THC and mono-split systems by systems with higher COP/EER.

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. The achieved results are:

- **Elementary School of Solum**: 96.2% of the consumed energy is ensured by renewable energy sources; 97.6% savings in final energy, 96.8% savings in primary energy and 98.0% savings in CO_2 emissions.
- **Municipal House of Culture**: 95.1% of the consumed energy is ensured by renewable energy sources; 97.2% savings in final energy, primary energy and CO_2 emissions.
- **Coimbra Town Hall**: 70% of the consumed energy is ensured by renewable energy sources; 80% savings in final energy, primary energy and CO_2 emissions.

A first calculation on the economic investment needed to carry out the selected renovation option is also given, as well as the cost savings and payback period. The achieved results are:

- **Elementary School of Solum**: Investment of 31,469 €, ensuring savings of 5,082 €/year and a simple payback period of 6.19 years.
- **Municipal House of Culture**: Investment of 396,656 €, ensuring savings of 65,742 €/year and a simple payback period of 6.03 years.
- **Coimbra Town Hall**: Investment of 723,949 €, ensuring savings of 42,739 €/year and a simple payback period of 16.61 years.

COIMBRA – PORTUGAL

CITY SUMMARY

Coimbra is the largest city in Centro Region of Portugal, with about 101,069 inhabitants in the urban area and 150,000 inhabitants in the area of the municipality. As the largest urban centre of a region of over 2 million inhabitants, Coimbra functions as regional capital. The presence of a university and other institutions of higher education designate Coimbra as "City of Knowledge".

Coimbra, located in the littoral axis of the country, is occupying a strategic and central position between the two metropolitan areas (Porto and Lisbon). The city has an excellent accessibility by motorways, railway, and seaport (Figueira da Foz) and also good traffic connections with Spain.

As a historic city Coimbra holds an important cultural and architectural heritage, which added to the fact that the city is being crossed by the River Mondego, gives to Coimbra a distinctive character and make her attractive for tourists. Coimbra's environmental quality is reinforced by a friendly climate, positive indicators on air and noise, a variety of green spaces in the urban centre and the river landscape of the Mondego.

About 2/3 of the population of the municipality are concentrated in the urban centre, and the Margin Right shows the highest population densities. Population growth has been more intense in the urban centre of Coimbra, with the exception of its historic centre, where there is a decrease and an aging population in the remaining parishes with character distinctly urban. Coimbra is essentially a centre for services, which is reflected in the high proportion of companies in the service sector as well as an industrial activity negligible. Only 16% (versus 27% at national) societies belong to the Secondary sector and has a workforce that predominantly affects the Tertiary sector (78% of the population of Coimbra vs 60% nationally). The reason for this situation is linked on the one hand, with the presence of strong features in health, education, law, commerce and logistics, and public administration in Coimbra and secondly, with an industrial sector that declined in the past decade and currently has little weight in the county - Moreover, about one third of the working population of the secondary sector is integrated in the construction sector.

Table 1 presents the general data related with the surface, population and climate.

TABLE 1: SURFACE, POPULATION AND CLIMATE DATA FROM COIMBRA

Surface Area:	319.41 km²
Population of the Municipality	143,396 inhabitants according to census 2011
Annual Heating Degree Days	1,460, Base Temperature 20 °C
Annual Cooling Degree Days	1,200, Base Temperature 24 °C
Population Density	448.94 Inhabitants/km²
Climate Area	Medium, according to DIR.2009/125/CE
Outdoor average T °C in winter	0-15 °C
Outdoor average T °C in summer	18-35°C

A. Elementary School of Solum

1. Building General Description

1.1. Location

The Elementary School of Solum (Escola Básica do 1º Ciclo da Solum) was built in the 1950s. Until the 1970s this was an annex school to the teacher training colleges dedicated to pedagogical training. In the 1990s it was converted into an Elementary School. The construction of refectory and a partial renovation of the building was done 10 years ago. Figure 1 presents the front façade of the building.

FIGURE 1: ELEMENTARY SCHOOL OF SOLUM

The building is located in the East side of the city, near to the Stadium and a commercial area. Table 2 presents the main location data of the building. Figure 2 and Figure 3 present the location in the city map and aerial view.

TABLE 2: LOCATION DATA OF THE BUILDING

Address	Rua Infanta D. Maria, 3030-330 Coimbra, Portugal
Coordinates	40.206128, -8.405372
Google Maps	www.google.pt/maps/@40.2059521,-8.4054218,118m/data=!3m1!1e3

FIGURE 2: LOCATION IN THE CITY (MAP)

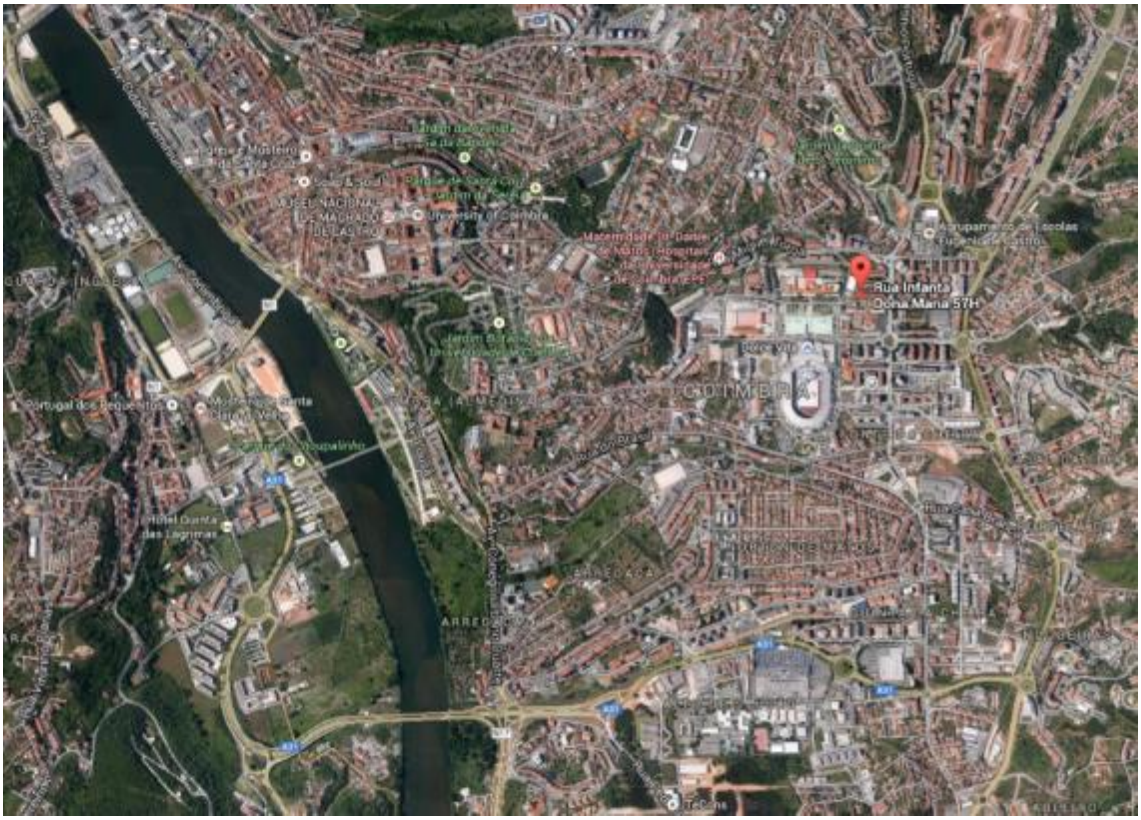


FIGURE 3: LOCATION IN THE CITY (AERIAL VIEW)

1.2. Shape and Orientation

Figure 4 presents the plan view and Figure 5 presents the aerial view of the building. It is constituted by 2 buildings with 39.8 x 9.5m each and 1 building (refectory) with 2 areas of 9.73 x 6.5 m and one of 7.15 x 2.15 m.

FIGURE 4: PLAN VIEW

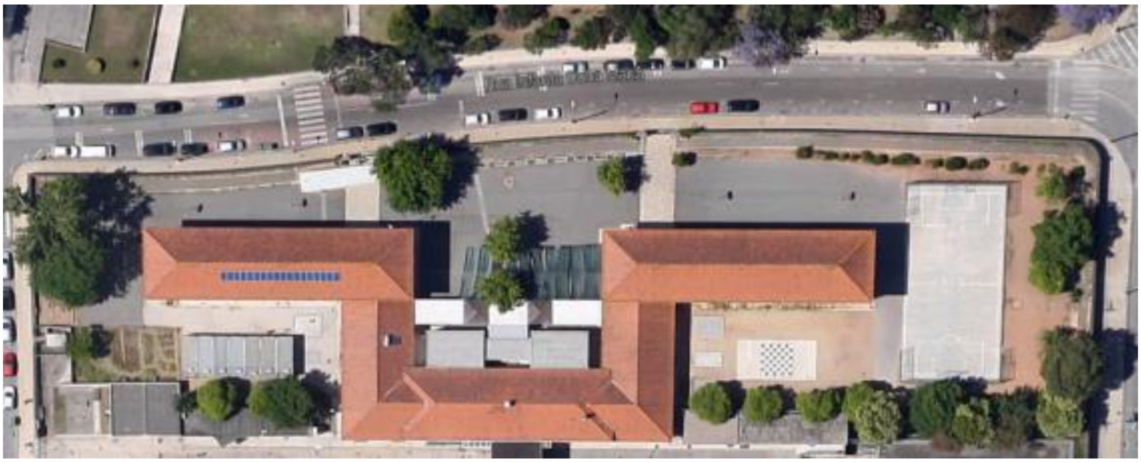


FIGURE 5: AERIAL VIEW

Figure 6 presents the elevation plan of the building, which has 2 floors in the 2 main buildings and 1 floor in the refectory building.

FIGURE 6: ELEVATION PLAN

As can be seen in Figure 7 the building is oriented along an east–west axis with the main façade in the north.

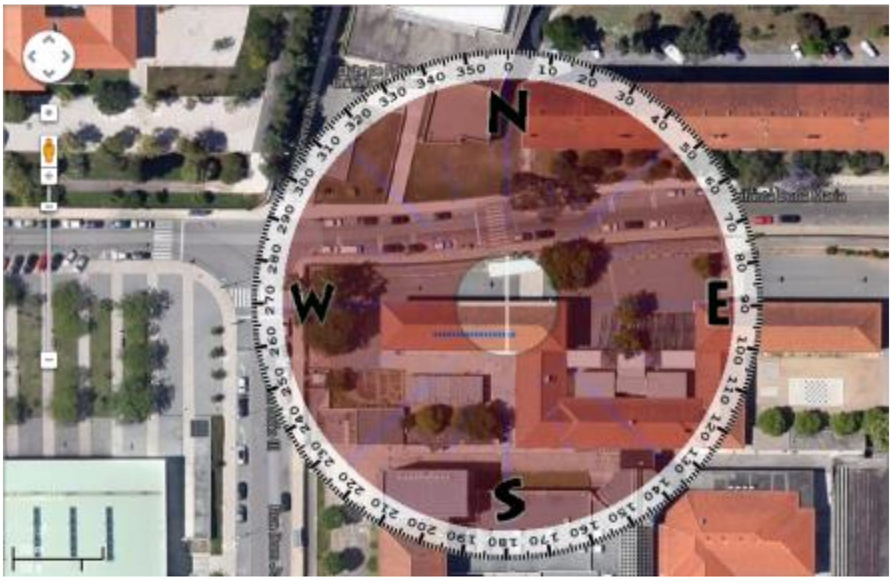


FIGURE 7: ORIENTATION OF THE MAIN FAÇADE

1.3. Area and Volume

The building has total area of about 1,655 m^2 (756 m^2 in each block and 142 m^2 in the refectory) and a volume of 6,269.21 m^3 (2,828.19 m^3 in each block and 612.84 m^3 in the refectory).

As can be seen in Figure 5 the roof is of ceramic tile and has a surface of 898 m^2.

1.4. Current Use

The building is an elementary school. As can be seen in Figure 8 the building is divided in 3 main areas: 2 blocks of classrooms and the refectory.

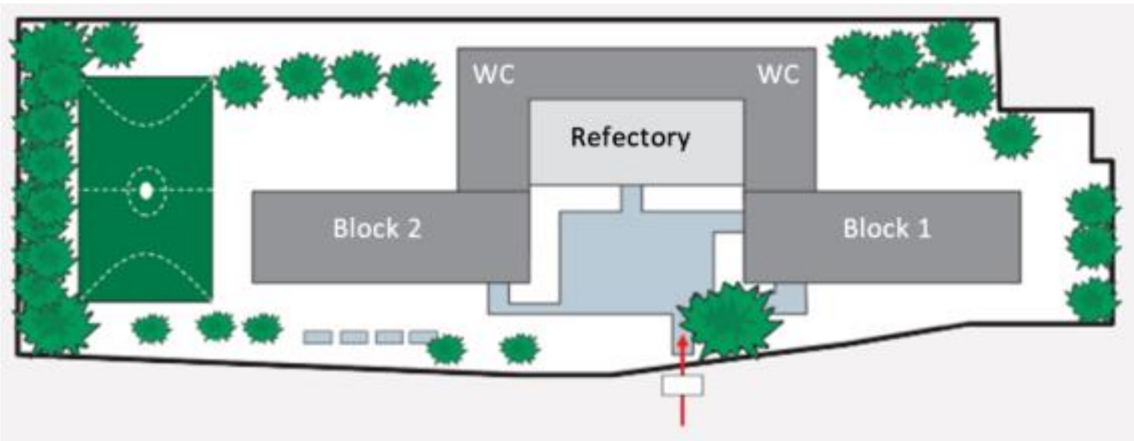


FIGURE 8: PLAN VIEW WITH SHOWING THE DIFFERENT AREAS OF THE BUILDING

Block 1 (Figure 9 and Figure 10) has the following rooms:

- 8 classrooms (6, 7, 8, 11, 13, 14, 15, 16)
- Teachers' room (9)
- Special education room (1, 11)
- Office of the parents' association (2)
- Bathroom (3)

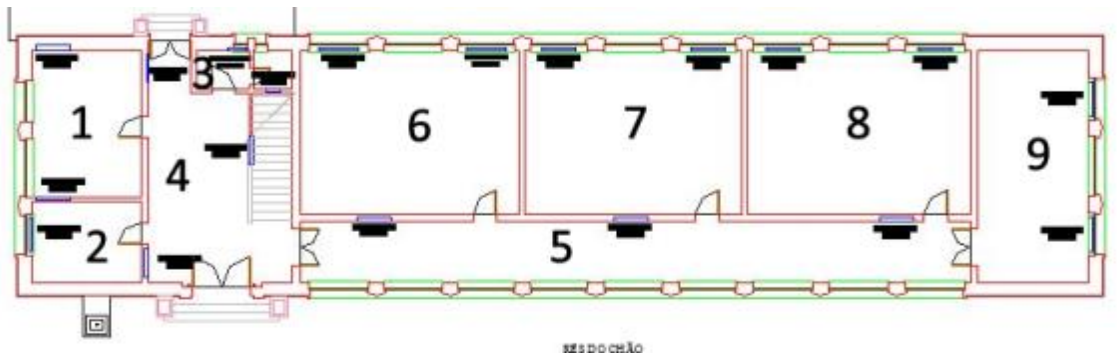


FIGURE 9: ROOMS USE IN BLOCK 1, FLOOR 0

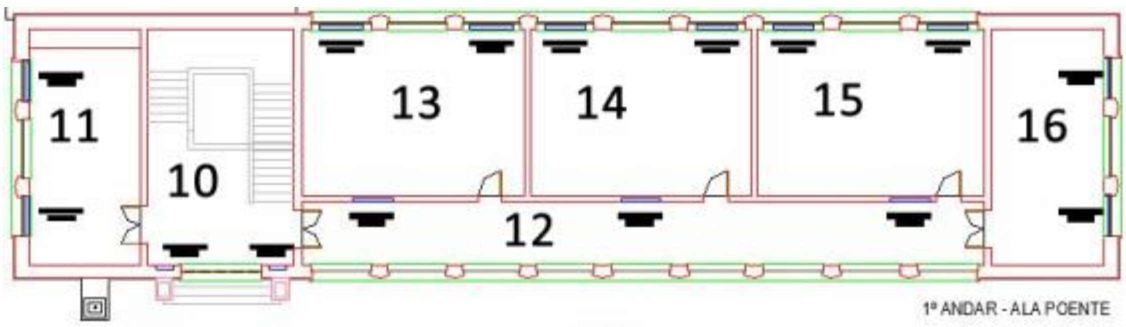


FIGURE 10: ROOMS USE IN BLOCK 1, FLOOR 1

Block 2 (Figure 11 and Figure 12) has the following rooms:

- 5 classrooms (28, 29, 34, 36, 37)
- Photocopies room (23)
- Coordination room (26)
- Library (30)
- Media library (31)
- Office of psychology (38)
- Guidance services (39)
- Storage room (16)

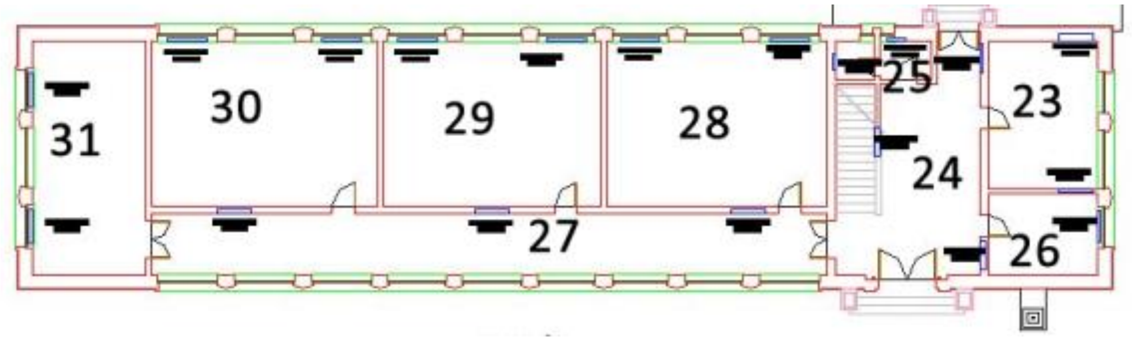


FIGURE 11: ROOMS USE IN BLOCK 2, FLOOR 0

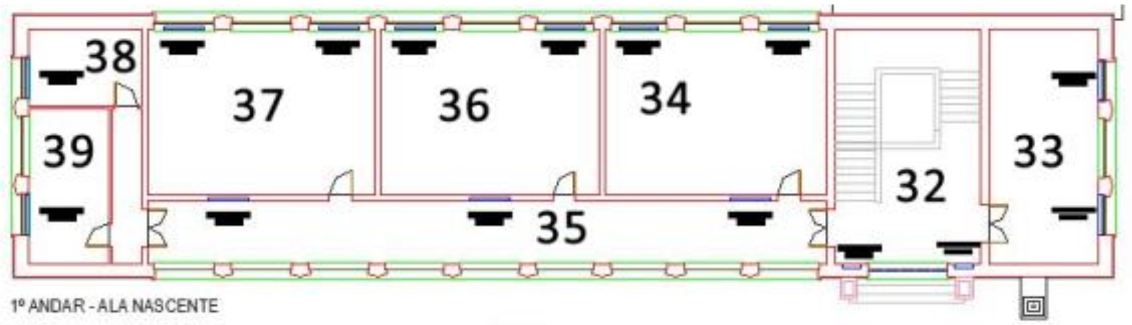


FIGURE 12: ROOMS USE IN BLOCK 2, FLOOR 1

The refectory and other exterior areas (Figure 13) are:

- Refectory with 2 rooms (40)
- 4 bathrooms - 2 male and 2 female (17, 19)
- Outdoor porch (20, 21, 22)
- Reception (41)
- Prefabricated building used by the Family Support project (18)

FIGURE 13: USES IN REFECTORY AND EXTERIOR AREAS

The Prefabricated building used by the Family Support project (area 18) is not managed by the Municipality. However, they receive electricity from the school (Figure 14).

FIGURE 14: PREFABRICATED BUILDING FROM THE FAMILY SUPPORT PROJECT

The school has about 300 students.

The schedule of the daily activities (Monday to Friday) is:

- Classes – 9h00 to 12h30 and 14h00 to 16h00
- Lunch – 12h30 to 14h00
- Extra-curricular activities – 16h30 to 17h30
- Family support – 7h30 to 9h00 and 17h30 to 19h00

The periods of classes during 2014/2015 are:

- 1st period – September, 15th to December, 16th
- 2nd period – January, 5th to March, 20th
- 3rd period – April, 7th to June, 12th

Outside these periods the use of the building is very low.

2. Current Building Conditions

2.1. Constructive Building Characteristics

2.1.1. Envelope Elements

The walls of each block have a total surface of 734 m², of which 182 m² is transparent (24.8%). The walls of the refectory have total surface of 260 m², of which 69 m² is transparent (26.5%). In the total, the walls have a surface of 1,728 m², of which 433 m² is transparent (25%).

The external walls are made of breeze blocks and bricks and have a thickness of 55 to 60 cm in the 2 blocks and of 35 to 55 cm in the refectory.

Table 3 presents the considered heat loss for transmission to the outside in the envelope.

TABLE 3: HEAT LOSS FOR TRANSMISSION TO THE OUTSIDE IN THE ENVELOPE

Structure	Orient.	A	U	Abs.	A.U.A.Rse	U.A.
		m²	W/m² ºC	α	W/ ºC	W/ ºC
Wall - Block1&2	N	295.50	0.29	0.6	2.06	85.7
Wall - Refectory	N	131.20	0.29	0.6	0.91	38.0
Wall - Block1&2	W	71.50	0.29	0.4	0.33	20.7
Wall - Refectory	W	26.85	0.29	0.4	0.12	7.8
Wall - Block1&2	S	295.50	0.29	0.4	1.39	86.6
Wall - Refectory	S	131.20	0.29	0.4	0.61	38.0
Wall - Block1&2	E	71.50	0.29	0.4	0.33	20.7
Wall - Refectory	E	26.85	0.29	0.4	0.12	7.8
Roof - Block1&2	-	378.10	0.50	0.4	3.02	189.1
Roof - Refectory	-	141.90	0.50	0.4	1.14	71.0

2.1.2. Windows

All the window frames are aluminium with the exception of 2 windows, which have a wooden frame. These windows are located in the hall of floor 1 of each block.

All the windows are double glazed with the exception of 4 windows. These windows are located in the hall of floor 1 of each block and in the lateral of the refectory building.

In each block there are the following windows:

- 36 operable of 2.10 x 1.80 m
- 8 operable of 1.60 x 1.80 m
- 4 operable of 2.10 x 1.80 m
- 1 fixed of 2.90 x 2.55 m
- 2 fixed of 0.40 x 0.45 m

In the refectory there are the following Windows:

- 2 operable of 2.00 x 1.73 m
- 2 operable of 6.00 x 1.60 m
- 2 operable of 2.00 x 2.68 m

- 2 fixed of 1.16 x 2.64 m
- 4 fixed (they belong to other building) of 2.00 x 1.60 m
- 7 fixed (they belong to other building) of 1.15 x 1.60

Then, the total number of windows is:

- 72 operable of 2.10 x 1.80 m
- 16 operable of 1.60 x 1.80 m
- 8 operable of 2.10 x 1.80 m
- 2 fixed of 2.90 x 2.55 m
- 1 fixed of 0.40 x 0. 45 m
- 2 operable of 2.00 x 1.73 m
- 2 operable of 6.00 x 1.60 m
- 2 operable of 2.00 x 2.68 m
- 2 fixed of 1.16 x 2.64 m
- 4 fixed (they belong to other building) of 2.00 x 1.60 m
- 7 fixed (they belong to other building) of 1.15 x 1.60

Each block has one door in iron with glass of 2.34 x 2.78 m (front) and one door in wood (back) of 1.65 x 2.10 (Figure 15). The refectory has a door in aluminum of glass with 2.00 x 2.83.

FIGURE 15: DOORS OF EACH BLOCK

The windows directed to west and south have interior shutters (Figure 16). Some shading is also ensured by other building (south façade) and trees (south, east and west).

FIGURE 16: WINDOWS WITH SHUTTERS

Table 4 presents the considered heat loss for transmission to the outside in windows.

TABLE 4: HEAT LOSS FOR TRANSMISSION TO THE OUTSIDE IN WINDOWS

Structure	Orient.	A	U	F_g	A_{eq}	U.A.
		m^2	W/m² ºC		m^2	W/ ºC
Windows - Block1&2	N	75.44	2.8	0.67	50.5	211.2
Windows - Refectory	N	36.82	2.8	0.67	24.7	103.1
Windows - Block1&2	W	19.08	2.8	0.67	12.8	53.4
Windows - Refectory	W	3.060	2.8	0.67	2.1	8.6
Windows - Block1&2	S	68.40	2.8	0.67	45.8	191.5
Windows - Refectory	S	25.68	2.8	0.67	17.2	71.9
Windows - Block1&2	E	19.08	2.8	0.67	12.8	53.4
Windows - Refectory	E	3.060	2.8	0.67	2.1	8.6

2.1.3. Airtightness and Pathologies

The doors of the 2 blocks present airtightness problems. However, the circulation areas do not have any HVAC source.

The building does not present relevant pathologies.

2.2. Energy Systems

Table 5 to Table 8 present the electrical equipment available in each room / area.

TABLE 5: ELECTRICAL EQUIPMENT AVAILABLE IN EACH ROOM OF BLOCK 1

Room	Type	Equipment	Quantity
1	HVAC	Oil-Filled Radiator	1
1	ICT	Laptop	1
1	ICT	PC+CRT	1
1	ICT	Printer	1
1	Lighting	F120	2
2	Lighting	F120	1
3	Lighting	CFL	1
4	Lighting	F120	1
5	Lighting	F120	3
6	HVAC	Oil-Filled Radiator	1
6	ICT	PC+CRT	1
6	ICT	Printer	1
6	Lighting	F120	7
7	HVAC	Oil-Filled Radiator	1
7	ICT	PC+CRT	1
7	ICT	Printer	1
7	Lighting	F120	7
8	HVAC	Oil-Filled Radiator	1
8	ICT	PC+CRT	1
8	ICT	Printer	1
8	Lighting	F120	7
9	Cooking	Microwave Oven	1
9	Cooking	Refrigerator	1
9	Cooking	Vending Machine	2
9	ICT	PC+CRT	1
9	Lighting	F120	3
10	Lighting	CFL	1
10	Lighting	F120	1
11	HVAC	Fan Heater	2
11	ICT	Access point	1
11	ICT	PC+CRT	1
11	Lighting	F120	4
12	Lighting	F120	3
13	HVAC	Oil-Filled Radiator	1
13	ICT	PC+CRT	1
13	ICT	Printer	1
13	Lighting	F120	7
14	HVAC	Oil-Filled Radiator	1
14	ICT	PC+CRT	1
14	Lighting	F120	7
15	HVAC	Oil-Filled Radiator	1
15	HVAC	Fan Ventilator	1
15	ICT	PC+CRT	1
15	Lighting	F120	7
16	Lighting	F120	3
17	Lighting	F150	2
18	HVAC	AC 9000 BTU	7

18	Lighting	F120	6
19	Lighting	F150	2

TABLE 6: ELECTRICAL EQUIPMENT AVAILABLE IN EACH ROOM OF BLOCK 2

Room	Type	Equipment	Quantity
22	Lighting	CFL	6
23	ICT	PC+TFT	1
23	ICT	Photocopier	1
23	ICT	Rack / Server	1
23	Lighting	F120	2
24	Lighting	F120	1
25	Lighting	CFL	2
26	ICT	PC+TFT	1
26	ICT	Printer	1
26	Lighting	F120	1
27	HVAC	Oil-Filled Radiator	1
27	ICT	PC+TFT	1
27	ICT	Printer	1
27	Lighting	F120	3
28	Lighting	F120	7
29	ICT	PC+TFT	1
29	ICT	Printer	1
29	Lighting	F120	7
30	ICT	Access Point	1
30	ICT	PC+TFT	1
30	Lighting	F120	6
31	ICT	PC+CRT	4
31	Lighting	F120	2
32	Lighting	CFL	1
32	Lighting	F120	1
33	Others	Microscope	9
33	ICT	PC+CRT	3
33	ICT	PC+TFT	1
33	Lighting	F120	4
34	HVAC	Oil-Filled Radiator	1
34	ICT	Video projector	1
34	Lighting	F120	3
35	Lighting	F120	7
36	HVAC	Oil-Filled Radiator	1
36	ICT	PC+CRT	1
36	ICT	Printer	1
36	Lighting	F120	7
37	HVAC	Oil-Filled Radiator	1
37	ICT	PC+CRT	1
37	ICT	Printer	1
37	Lighting	F120	7
38	HVAC	Oil-Filled Radiator	1
38	ICT	PC+CRT	1

38	ICT	Printer	1
38	Lighting	F120	1
39	HVAC	Oil-Filled Radiator	1
39	ICT	PC+CRT	1
39	ICT	Printer	1
39	Lighting	F120	1

TABLE 7: ELECTRICAL EQUIPMENT AVAILABLE IN EACH ROOM OF THE REFECTORY

Room	Type	Equipment	Quantity
40	Cooking	Dishwasher	1
40	Cooking	Microwave Oven	1
40	Cooking	Refrigerator	1
40	Cooking	Water Heater	1
40	Lighting	CFL	2
40	Lighting	Emergency Block	4
40	Lighting	F120	1
40	Lighting	F60	6

TABLE 8: ELECTRICAL EQUIPMENT AVAILABLE IN EXTERIOR AREA

Room	Type	Equipment	Quantity
20	Lighting	F120	1
21	Lighting	F120	1
22	Lighting	CFL	6
Wall	Lighting	CFL	15
41	Lighting	F120	1

2.2.1. Lighting

The lighting system is mainly constituted by fluorescent linear T8 lamps with electromagnetic ballast. For instance, each classroom has 7 fluorescent linear T8 lamps (Figure 17) with 6 at the ceiling and one on the board. There are also some Compact Fluorescent Lamps and emergency lighting (just in the refectory building).

Regarding the fluorescent linear lamps, usually each luminary has just one lamp. The exception are the F60 lamps (used in the refectory), since each luminaire (6) have 2 lamps. However, in each luminary one of the lamps was disconnected. In the exterior of the buildings the lighting is ensured by fluorescent linear T8 lamps (F120) and Compact Fluorescent Lamps.

FIGURE 17: LIGHTING IN A CLASSROOM

Table 9 presents the types and quantities of lamps, as well as the total installed power.

TABLE 9: TYPES AND QUANTITIES OF LAMPS

Lamp Type	Quantity n	Power W
Fluorescent Linear T8 F150	4	270.4
Fluorescent Linear T8 F120	127	5,943.6
Fluorescent Linear T8 F60	12	280.8
Compact Fluorescent	28	504
Emergency	4	48
Total	**175**	**7,046.8**

2.2.2. HVAC

The 2 main blocks have old wall radiators with circulation of hot water (Figure 18). In the plans of the buildings it is possible to see the location of each radiator. However, the system is no longer operational and therefore these buildings do not have any source of central heating.

FIGURE 18: OLD RADIATORS INSTALLED IN THE 2 BLOCKS

To ensure the heating during the coldest days the classrooms have one oil-filled radiator (Figure 19). Only one classroom has a fan ventilator to be used during summer. The type and quantity of HVAC devices available in the 2 blocks is:

- 9 oil-filled radiators of 1 kW
- 4 oil-filled radiators of 2 kW
- 1 fan heater of 1 kW
- 1 fan ventilator

FIGURE 19: OIL-FILLED RADIATORS

The refectory building have central heating (Figure 20), ensured by a boiler using natural gas. The combustion takes place in an open chamber and the air required is taken from the boiler room itself. However, the boiler is not installed in the refectory building, it is installed inside the reception (room 41), which is 30 meters away (straight-line distance) from the refectory.

FIGURE 20: HEATING IN THE REFECTORY

The technical data of the boiler (VICTORIA 20 model) is presented in Table 10.

TABLE 10: CHARACTERISTICS OF THE BOILER

Central Heating Mode	
Heat Output	Adjustable from 7,000 kcal/h (8.1 kW) to 20,000 kcal/h (23.3 kW)
Maximum circuit pressure	3 bar
Maximum working temperature	90 °C
Filling pressure	1.5 bar
Domestic Hot Water (DHW) Mode	
Heat Output	Adjustable from 7,000 kcal/h to 20,000 kcal/h.
Maximum circuit pressure	7 bar
Maximum working temperature	60 °C
DHW production	Δt Þ 25 °C Þ 13.3 l/min Δt Þ 30 °C Þ 11.1 l/min Δt Þ 35 °C Þ 9.5 l/min
Minimum operating pressure and flow rate for ignition	0.2 bar and 3 l/min

Therefore, the total heating power in the building is 41.3 kW.

The prefabricated building from the Family Support project (area 18) has air conditioning (identified in Table 5). However, such devices are not owned or managed by the Municipality.

2.2.3. ICT

The communication devices but also other electronic devices, such as computers, printers, etc. are considered as ICT (Information and Communications Technologies). Each classroom has at least one computer with one monitor (CRT or TFT). Some offices also have computers as well as printers. There are also access points and a rack/server to the wireless network and one classroom have a video projector. In terms of energy consumption the main device is a photocopier.

The type and quantity of ICT devices available in the two blocks is:

- 15 PC + CRT
- 6 PC + TFT
- 1 laptop
- 12 printers
- 1 video projector
- 2 access points
- 1 Rack/Server
- 1 Photocopier
- 9 microscopes

2.2.4. Others

In the refectory there are cooking appliances. However, since the meals are not prepared in the school (they receive it already prepared) the consumption of such equipment is not high. The equipment available in the refectory is just a refrigerator, a microwave oven, a dishwasher and a water heater. The water heating is mainly ensured by a solar thermal system (described in Section 2.3.3), being the electric water heater just a backup. The electric water heater (Videira MULTI-F Vertical model) has a capacity of 50 litters and a power of 1200 W. Then, the main consumption is due to the dishwasher (Comenda LF322M model) which has a maximum power of 5.45 kW (Table 11).

TABLE 11: CHARACTERISTICS OF THE DISHWASHER

Wash pump	0.45 kW
Tank capacity	21 l
Tank heater	2 kW
Booster capacity	8.2 l
Booster heater	5 – 2.5 kW
Total power	5.45 kW

There is also some cooking equipment in the teachers' room, such as a refrigerator, a microwave oven and 2 vending machines

2.3. Energy Consumption and Energy Generation

2.3.1. Electricity Consumption

The building receives electricity in Low Voltage. The characteristics of the contract are presented in Table 12.

TABLE 12: CHARACTERISTICS OF THE ELECTRICITY CONTRACT

Voltage Level	Normal Low Voltage
Contracted Power	34.5 kVA
Tariff Option	3 Periods
Cycle	Diary

To this tariff there are three tariff periods, which are presented in Table 13.

TABLE 13: SCHEDULE OF THE TARIFF PERIODS

Period	Winter	Summer
On-Peak	09h00 – 10h30 18h00 – 20h30	10h30 – 13h00 19h30 – 21h00
Mid-Peak	08h00 – 09h00 10h30 – 18h00 20h30 – 22h00	08h00 – 10h30 13h00 – 19h30 21h00 – 22h00
Off-Peak	22h00 – 08h00	22h00 – 08h00

In 2013 the building had an electricity consumption of about 30 MWh and an associated cost of about 6.7 k€. Table 14 presents the evolution of the electricity consumption since 2012. In Normal Low Voltage the meter reading is just ensured once every three months. The monthly billing is not always accurate, being based on forecasts. Then, the billing is corrected after the meter reading. This justifies the negative values and the small periods of billing (which are the small period of forecast after the last meter reading. Therefore, it is not possible to assess the yearly variation of the consumption. However, it is possible to observe that the consumption is higher during the winter due to the impact of the heating. The distribution between tariff periods is in average: 18.4% in on-peak; 58.0% in mid-peak; and 23.6% in off-peak. This shows that there is a high consumption outside the working period of the building.

TABLE 14: EVOLUTION OF THE ELECTRICITY CONSUMPTION SINCE 2012

Period	Days	Off-Peak	On-Peak	Mid-Peak	Total
2012-06-29 - 2012-07-27	29	503	393	1,140	2,036
2012-07-28 - 2012-07-31	4	303	-103	-441	-241
2012-08-01 - 2012-08-28	28	521	423	1,216	2,160
2012-08-29 - 2012-09-21	24	428	100	295	823
2012-09-22 - 2012-09-28	7	127	98	282	507
2012-09-29 - 2012-10-26	28	527	404	1,168	2,099
2012-10-27 - 2012-11-28	33	648	497	1,438	2,583
2012-11-29 - 2012-12-28	30	625	479	1,386	2,490
2012-12-29 - 2013-01-28	31	650	499	1,442	2,591
2013-01-29 - 2013-02-28	31	650	499	1,442	2,591
2013-03-01 - 2013-03-28	28	578	444	1,283	2,305
2013-03-29 - 2013-03-29	1	-167	901	3,115	3,849
2013-03-30 - 2013-04-26	28	480	404	1,192	2,076
2013-04-27 - 2013-05-28	32	547	460	1,357	2,364
2013-05-29 - 2013-06-18	21	641	375	712	1,728
2013-06-19 - 2013-06-28	10	186	150	438	774
2013-06-29 - 2013-07-26	28	527	424	1,237	2,188
2013-07-27 - 2013-08-28	33	630	508	1,480	2,618
2013-08-29 - 2013-09-27	30	575	464	1,351	2,390
2013-09-28 - 2013-09-28	1	113	-548	-1,867	-2,302
2013-09-29 - 2013-10-28	30	582	481	1,386	2,449
2013-10-29 - 2013-11-28	31	619	512	1,473	2,604
2013-11-29 - 2013-12-27	29	600	496	1,428	2,524
2013-12-28 - 2014-01-28	32	670	553	1,593	2,816
2014-01-29 - 2014-02-28	31	651	538	1,549	2,738
2014-03-01 - 2014-03-21	21	1,141	1,405	5,585	8,131
2014-03-22 - 2014-03-28	7	154	120	365	639
2014-03-29 - 2014-04-28	31	639	500	1,518	2,657
2014-04-29 - 2014-05-28	30	615	480	1,459	2,554

Figure 21 presents the consumption profile during one week (from Thursday to Thursday) in November.

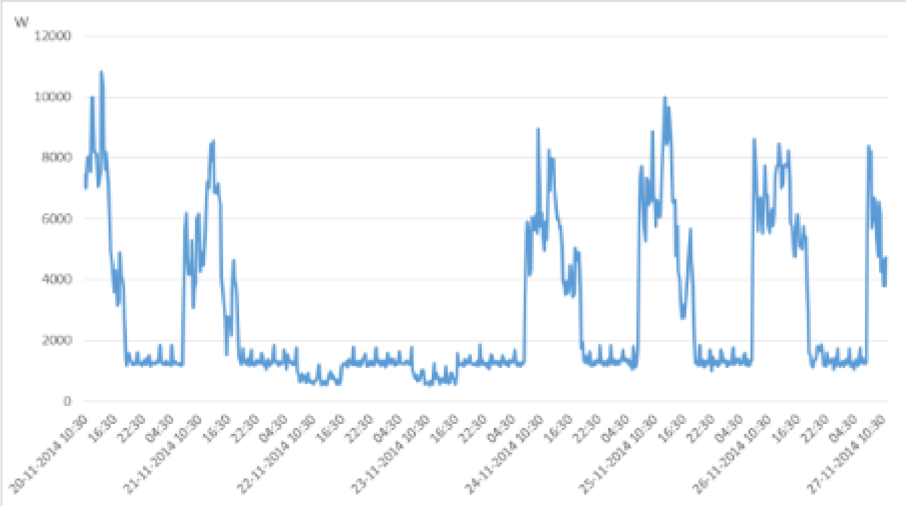


FIGURE 21: CONSUMPTION PROFILE IN THE MAIN ELECTRICAL BOARD

Figure 22 presents the disaggregation of electricity consumption between uses, based on the data available from consumption monitoring and use of electrical equipment. The major consumption is in lighting, followed by HVAC and ICT. In this disaggregation the prefabricated building is considered as an independent category since it is not part of the school and is not managed by the Municipality. However, considering also the disaggregation of the consumption in the prefabricated building, since its consumption is mainly HVAC, the HVAC becomes the major consumption, as can be seen in Figure 23.

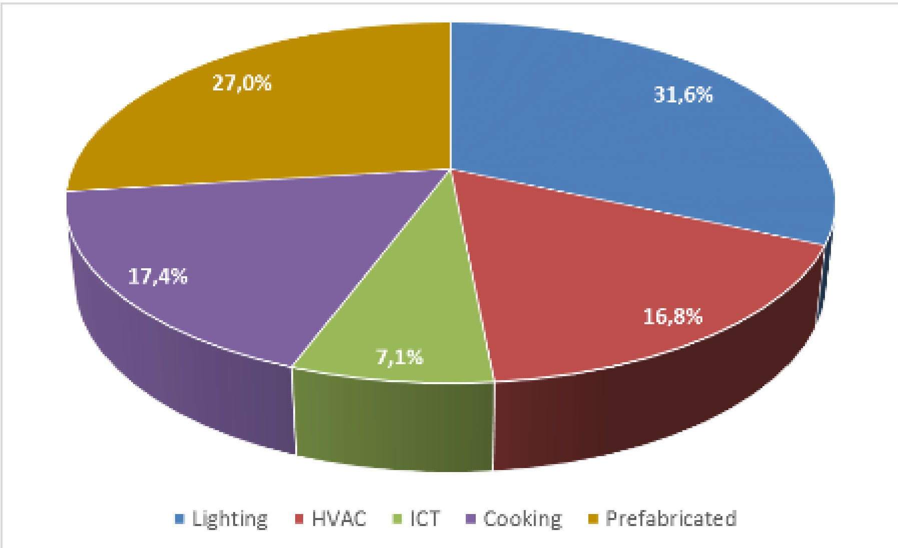


FIGURE 22: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES (EXCLUDING THE PREFABRICATED BUILDING)

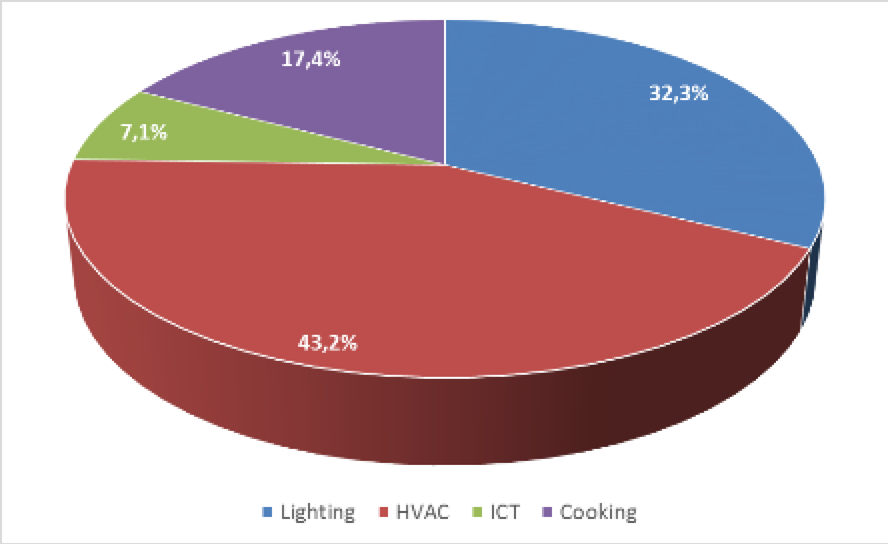


FIGURE 23: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES

Figure 24 presents the disaggregation of electricity consumption between uses, excluding the prefabricated building.

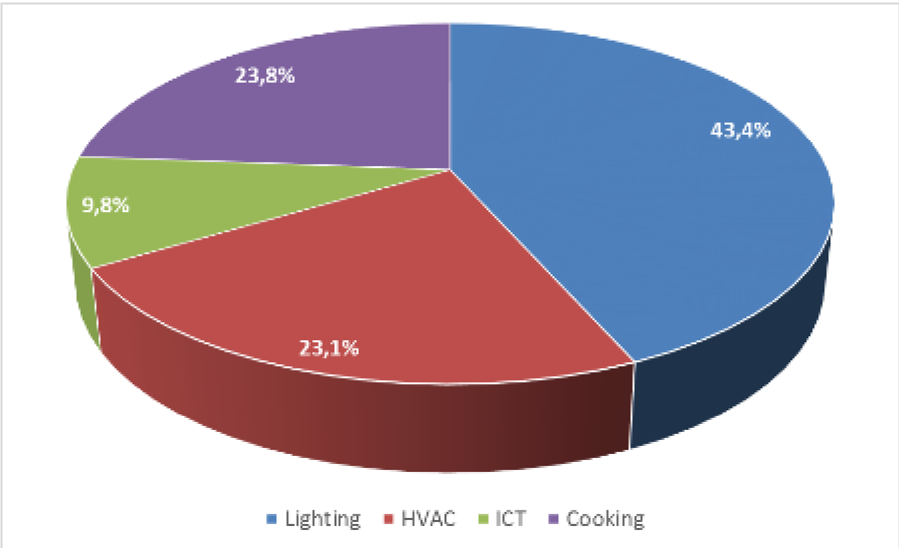


FIGURE 24: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES, EXCLUDING THE PREFABRICATED BUILDING

2.3.2. Gas/Oil Consumption

All the natural gas is consumed in the boiler and used to ensure the heating of the refectory building. Thus, the consumption of natural gas is concentrated in the winter and mainly in January and February. The consumption in 2013 was 16,775 kWh (1,548 m^3) with an associated cost of 1,778 €.

2.3.3. Renewable Energy Sources

The building has a PV system of 4,230 W with all the generated energy being sold to the grid. Table 15 presents the main characteristics and Figure 25 the electrical scheme of the PV system.

TABLE 15: CHARACTERISTICS OF THE PV SYSTEM

Quantity of modules	18
Type of modules	Polycrystalline Silicon
Total power	4,230 W
Total area	29.18 m^2

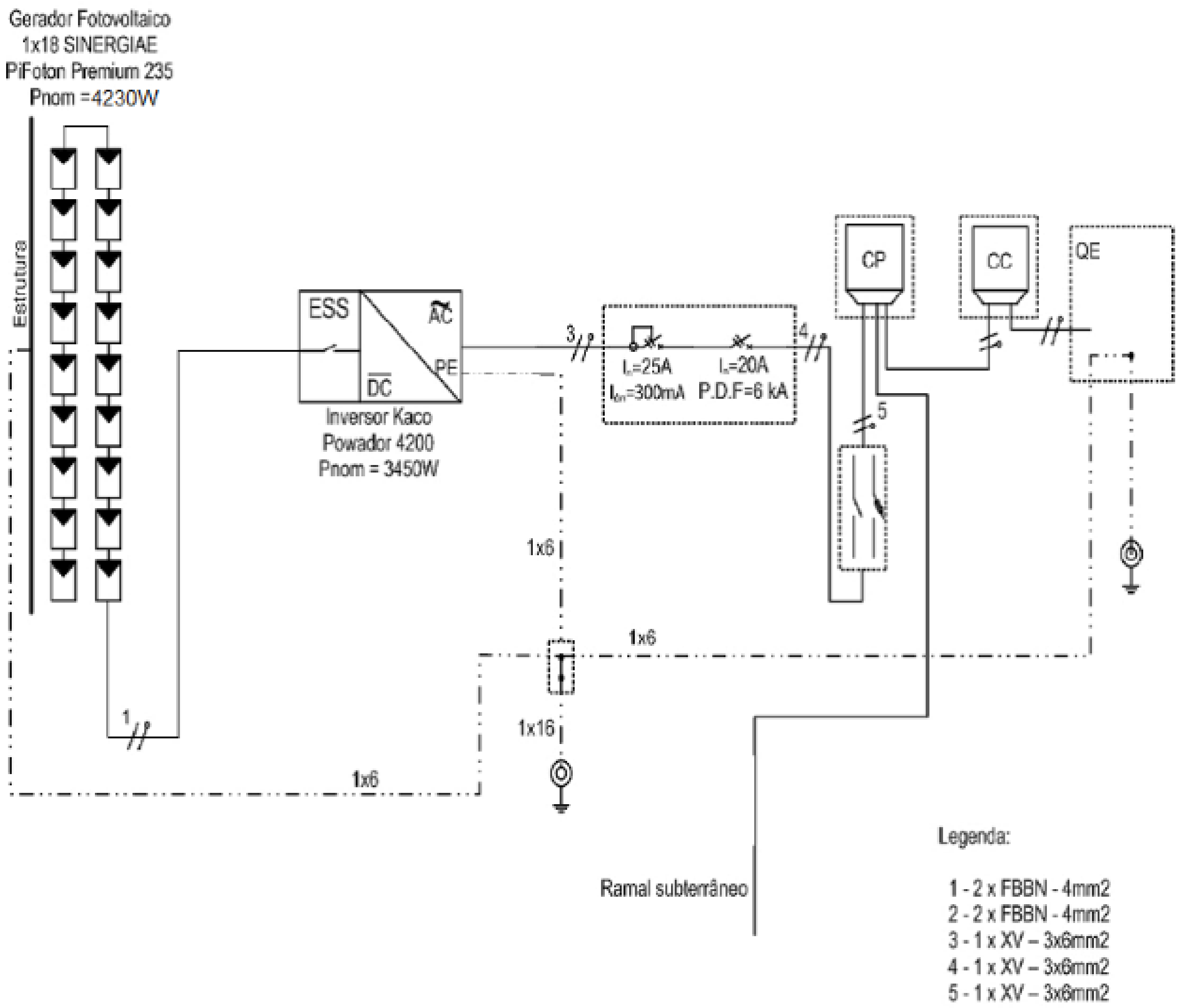


FIGURE 25: ELECTRICAL SCHEME OF THE PV SYSTEM

The systems uses 18 modules SINERGIAE PiFoton Premium 235 (Table 16) and an inverter Kaco Powador 4200 S (Table 17).

TABLE 16: CHARACTERISTICS OF THE PV MODULES

Electrical Characteristics	
Minimum guaranteed power	235 W
Voltage at maximum power	29.58 V
Current at maximum power	7.95 A
Short-circuit current	8.57 A
Open-circuit voltage	38.10 V
Mechanical Characteristics	
Dimensions	1,639 x 989 x 35 mm
Weight	20 kg

TABLE 17: CHARACTERISTICS OF THE INVERTER

Nominal power AC	3,450 W
Maximum power DC	4,200 W
Maximum power AC	3,800 W
Nominal current AC	15 A
Maximum current AC	17.5 A
Nominal voltage AC	220 – 240 V
Maximum efficiency	95.8%

The PV system is installed in the south of Block 2 rooftop (Figure 26) and the PV panels have an azimuth of -15º relatively to South and with slope angle of 30º.

FIGURE 26: AERIAL VIEW OF THE PV PANELS AND SOLAR THERMAL COLLECTOR

Figure 27 presents the monthly average generation of the PV system. It ensures an average yearly generation of 6,100 kWh which was 20% of the electricity consumption in 2013.

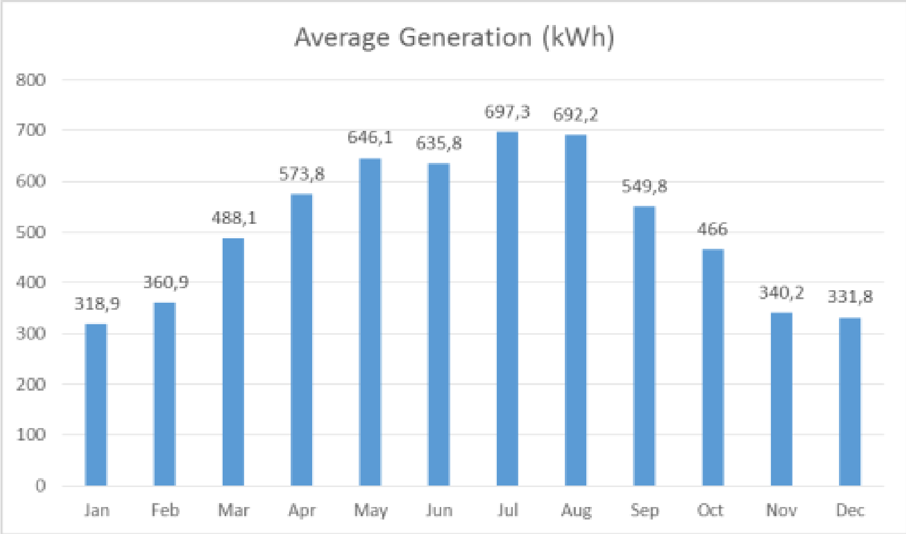


FIGURE 27: MONTHLY AVERAGE GENERATION OF THE PV SYSTEM

A solar thermal collector of 2 m^2 was installed together with the PV system, since it is required to receive the special tariff for micro PV systems.

As can be seen in Figure 26 it was not installed oriented to South, but to East with the aim of minimizing the visual impact, as required by the municipality architects. However, this has a high impact on the system performance.

It is a system of natural circulation using a solar collector Ariston Kairos Thermo 200-1 TT. Figure 28 presents the dimensions of the solar collector and Table 18 presents its main technical characteristics.

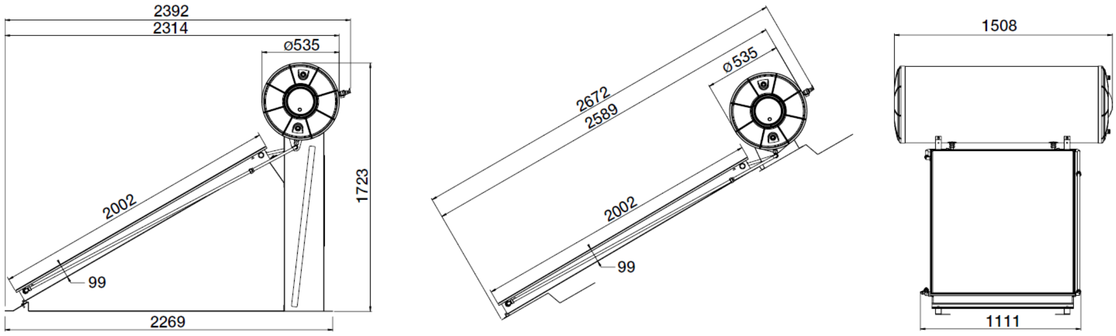


FIGURE 28: SOLAR COLLECTOR DIMENSIONS

The solar thermal concentrator is used to supply hot water to the kitchen of the refectory, having as backup an electric water heater.

TABLE 18: TECHNICAL CHARACTERISTICS OF THE SOLAR COLLECTOR

Collectors gross surface	2.01 m^2
Collectors aperture surface	1.73 m^2
Empty mass (ground installation)	140 kg
Empty mass (roof installation)	127 kg
Solar circuit capacity	7.4 l
Hot water storage tank capacity	202 l
DHW circuit max. pressure	8 bar
Solar circuit safety valve calibration	1.5 bar
Heat loss	2.2 kWh/24h

2.3.4. Other Generation

The building does not have any other source of generation.

2.3.5. Final Energy Consumption and CO_2 Emissions

During 2013 the buildings had an electricity consumption of 30,749 kWh. However, 27% of this consumption is the electricity sent to the prefabricated building and therefore it cannot be considered as a consumption of the studied building. Additionally, there was a consumption of 16,775 kWh of natural gas, being the total energy consumption 39,219 kWh (Table 19).

TABLE 19: ENERGY CONSUMPTION IN 2013

Consumption kWh	Including Prefabricated Building	Excluding Prefabricated Building
Electricity	30,749	22,516
Gas	16,775	16,775
Total	**47,504**	**39,219**

Table 20 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 - 2.5 (standard value approved for Portugal);
- natural gas to primary energy - 1.0 (standard value);
- electricity to CO_2 emissions - 139.89 g/kWh (average emissions associated with the electricity consumed in Portugal during 2013);
- natural gas to CO_2 emissions - 202 g/kWh (standard value).

TABLE 20: ENERGY PARAMETERS

	Final Energy kWh	Energy Dens. kWh/m^2	Primary Energy kWh	CO_2 Emissions kg CO_2 /kWh
Electricity	22,516	13.60	56,290	3,149.8
Gas	16,775	10.14	16,775	3,388.6
Generation	-6,100	-3.69	2,320	-853.3
Total	33,191	20.05	75,385	5,685.1

3. Renovation Scheme

3.1. Aim of the Renovation Plan

The objective of the renovation plan 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. However, since there is enough available roof area without shadings and with a good solar radiation levels the aim was redefined to achieve a minimum primary energy reduction of 95%, ensuring, at least, 95% of the consumption with renewable energy sources, therefore achieving almost a Zero Energy Level.

The following global constraints were taken into account in the design of the renovation plan:

- There are 7 prefabricated buildings in the exterior area of the school. Such buildings are not permanent constructions and do not belong to the Municipality, being managed by the Family Support project. However, they receive electricity from the school without any individual metering. Therefore, its consumption is included in the total consumption of the building, but such energy consumption cannot be considered as a consumption of the studied building. The consumption of the prefabricated buildings was assessed (considered to be 27% of the total energy consumption) and subtracted from the total considered for the building. Therefore, the consumption level considered in the renovation plan excludes the consumption of the prefabricated buildings.

3.2. Energy Demand Reduction

3.2.1. Opaque Envelope

The building was recently renovated and therefore the opaque envelope does not present major problems. Additionally, since the building does not have any centralized HVAC system the improvement of the envelope would not lead to a major reduction of energy consumption in heating and cooling. Therefore, the improvement of the opaque envelope was not considered in the renovation plan.

3.2.2. Openings

The building already has double glazed windows.

The main entrance doors of the 2 blocks are not airtight and present unintentional infiltration of air into the building. However, the circulation areas do not have any HVAC source and its replacement is not traduced in any energy saving. Therefore, the improvement of openings was not considered in the renovation plan.

3.2.3. Other Strategies

There are no other strategies considered in the renovation for the energy demand reduction.

3.3. Energy Systems

3.3.1. Lighting System

As previously presented the actual lighting system is mainly constituted by fluorescent linear T8 lamps with electromagnetic ballast (Table 21).

TABLE 21: TYPES AND QUANTITIES OF LAMPS ACTUALLY USED

Lamp Type	Quantity N	Power W
Fluorescent Linear T8 F150	4	270.4
Fluorescent Linear T8 F120	127	5,943.6
Fluorescent Linear T8 F60	12	280.8
Compact Fluorescent	28	504
Emergency	4	48
Total	**175**	**7,046.8**

Regarding the retrofit of the lighting system 2 scenarios were considered:

- Scenario 1 - Replacement of all T8 lamps with electromagnetic ballast by T5 lamps with electronic ballast;
- Scenario 2 - Replacement of all lamps by LEDs.

In scenario 1,143 lamps and ballasts have to be replaced. Table 22 presents the lamps and ballasts to be installed and Table 23 show the new distribution of lamps. As can be seen the total power decreases to 4790 W (reduction of 32%).

TABLE 22: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN SCENARIO 1

Lamp Type	Quantity n	Lamp W	Lamp+Ballast W
Fluorescent Linear T5 F150	4	49	56
Fluorescent Linear T5 F120	127	28	30
Fluorescent Linear T5 F60	12	14	17

TABLE 23: TYPES AND QUANTITIES OF LAMPS CONSIDERED IN SCENARIO 1

Lamp Type	Quantity n	Total Power W
Fluorescent Linear T5 F150	4	224
Fluorescent Linear T5 F120	127	3,810
Fluorescent Linear T5 F60	12	204
Compact Fluorescent	28	504
Emergency	4	48
Total	**175**	**4,790**

In scenario 2, all the 175 lamps have to be replaced. Table 24 presents the lamps to be installed and Table 25 show the new distribution of lamps. As can be seen the total power decreases to 3,026.4 W (reduction of 57%).

TABLE 24: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN SCENARIO 2

Lamp Type	Quantity n	Lamp W
LED Linear F150	4	24
LED Linear F120	127	20
LED Linear F60	12	10
LED Bulb	28	9.5
LED Emergency	4	1.1

TABLE 25: TYPES AND QUANTITIES OF LAMPS CONSIDERED IN SCENARIO 2

Lamp Type	Quantity n	Total Power W
LED Linear F150	4	96
LED Linear F120	127	2,540
LED Linear F60	12	120
LED Bulb	28	266
LED Emergency	4	4.4
Total	**175**	**3,026.4**

Table 26 presents the yearly consumption with lighting in the 2 scenarios, as well as the percentage of achievable savings and the percentage of consumption with lighting in the several scenarios. Such energy consumptions were simulated considering the actual usage profile for each lamp type and room of the building. As can be seen, scenario 1 ensures 31.3% and scenario 2 ensures 57.9% of energy savings.

TABLE 26: YEARLY CONSUMPTION WITH LIGHTING IN THE 2 SCENARIOS

	Actual	Scenario 1	Scenario 2
Consumption (kWh)	9,897	6,798	4,167
Savings (kWh)	-	3,099	5,730
Savings (%)	-	31.3%	57.9%

3.3.2. HVAC System

The main opportunity of renovation in the HVAC is the replacement of the gas boiler used in the central heating of the refectory. It is possible to replace this boiler directly by a heat pump without the need of a total refurbishment of the system. It was considered that the actual boiler has a COP of 0.90, replaced by a heat pump of 11 kW with a COP of 3.57. Table 27 presents the yearly consumption in the refectory heating in the actual and retrofit scenarios. As can be seen, the retrofit ensures 70.8% of energy savings.

The other areas of the building do not have central heating, being the heating in the classrooms during the coldest days ensured by one oil-filled radiator. The building does not have cooling, but this is not a major problem since in the months with higher temperatures the building is not used (there are no classes). However, the option to replace such oil-filled radiators by heat pumps, which can also be used for cooling, would create new energy consumption. This renovation could increase the comfort in the building.

However, it cannot be considered as an option to increase the energy efficiency, since the total energy consumption would increase and therefore it is not included in the renovation plan.

TABLE 27: YEARLY CONSUMPTION IN THE REFECTORY HEATING

	Actual	Scenario 1
Consumption (kWh)	16,775	4,901.8
Savings (kWh)	-	11,873.2
Savings (%)	-	70.8%
% Energy Cons. excl PF	42.8%	17.9%
% Energy Cons. incl. PF	35.3%	13.8%

3.3.3. ICT and Others

ICT and other appliances (mainly PCs, monitors and printers) do not represent individually a large share of energy consumption and therefore the achieved savings with such appliances would not have a major impact on the total energy consumption. The replacement of such appliances by new devices is not cost-effective just from the energy savings point of view and therefore this is not considered in the renovation plan. However, in the regular replacement of ICT appliances it is recommended to install just ICT appliances with lower energy consumption.

From the energy savings point of view, the most cost-effective solution is the installation of devices to reduce the standby consumption of ICT appliances, the so called standby killers. However, the potential savings achieved with such devices do not depend on the technology, but on the users' behaviour and therefore a reliable assessment of savings is not possible. Therefore, such measure is not included in the renovation plan, due to the difficulty of assessment, but its implementation is recommended.

The cooking appliances also do not have a major impact on the total energy consumption and the quantity of equipment is low. Therefore, its renovation was not included in the plan. However, in the regular replacement of such appliances it is recommended to install just appliances with lower energy consumption (with label A+ or better).

3.4. Renewable Energy Sources

3.4.1. PV Generation

Figure 29 shows the different roof areas of the building. Area 12 belongs to other building and cannot be considered. In area 11 there is some shading due to the other building (area 12) and therefore this is not a good location to implement PV panels. Areas 1, 2, 4, 5, 6, 8, 9, 10 do not have a good orientation and the implementation of PV panels in such areas will require additional structures to improve the orientation of the panels which would have a high visual impact. Therefore, only areas 3 and 7 were selected to the implementation of PV panels.

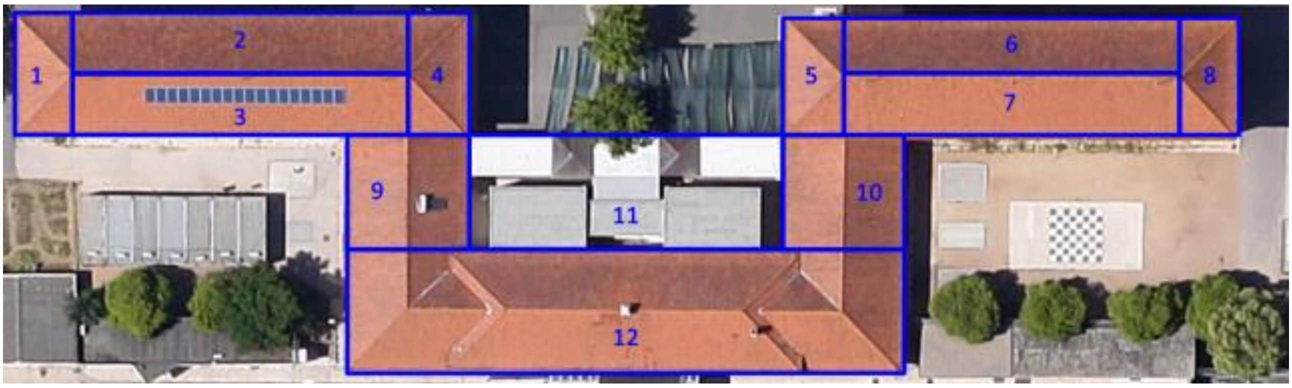


FIGURE 29: ROOF AREAS

In area 3 there is already a PV system and the best solution is to keep such system and to increase the number of PV panels using the available area (Figure 30).

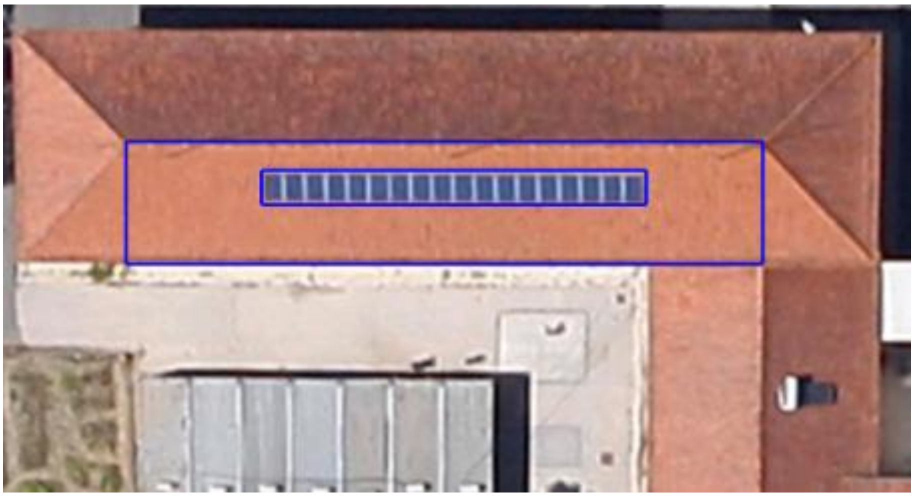


FIGURE 30: AREA FOR IMPLEMENTATION OF PV PANELS

The actual PV system has 17.8 x 1.64 m (18 panels with 0.989 x 1.639 m) and since area 3 has 30.33 x 5.19 m it would be possible to install 90 PV panels (3 rows with 30 PV panels). However, to do it, the actual PV system would have to be moved and the installation and maintenances of panels would be difficult due to the reduced area between the rows of panels. Therefore, without the need to move the actual PV system, it is possible to increase the row of PV panels to 27 panels and it is possible to add another row. Such structure can also be used in area 7. A more conservative option could be to just duplicate the row of 18 PV panels, using the same structure also in area 7.

Therefore, 2 scenarios were considered:

- Scenario 1: duplicate the row of 18 panels and use the same structure in area 7 (total of 72 panels).
- Scenario 2: increase the row for 27 panels, duplicate the row and repeat the structure in the area 7 (total of 108 panels).

Both scenarios were simulated with PVSYST using the following parameters for the site and simulation (Table 28 and Table 29, respectively).

TABLE 28: SITE PARAMETERS

Geographical Site	Coimbra
Country	Portugal
Latitude	40.1°N
Longitude	8.3°W
Time	Defined as Legal Time
Time zone	UT+1
Altitude	141 m
Albedo	0.20
Meteo data	Coimbra, Synthetic Hourly data

TABLE 29: SIMULATION PARAMETERS

Collector Plane Orientation	Tilt 30° Azimuth -15°
Horizon	Free Horizon
Near Shadings	No Shadings

In the simulation of scenario 1, it was considered series of 18 modules and 4 strings in parallel. Table 30 presents the PV array characteristics, Table 31 presents the inverter characteristics and Table 32 presents the PV array loss factors.

TABLE 30: PV ARRAY CHARACTERISTICS IN SCENARIO 1

PV module	Si-poly
Model	SINPRIME PREMIUM 235[1]
Manufacturer	SINERGIAE
Number of PV modules	In series 18 modules In parallel 4 strings
Total number of PV modules	72
Unit Nom. Power	235 Wp
Array global power	Nominal (STC) 16.92 kWp At operating cond. 15.21 kWp (50°C)
Array operating characteristics (50°C)	U mpp 485 V I mpp 31 A
Total area	Module area 117 m² Cell area 43.2 m²

[1] The SINPRIME module is equivalent to the PiFoton

TABLE 31: INVERTER CHARACTERISTICS IN SCENARIO 1

Model	Powador 4200
Manufacturer	KACO new energy
Characteristics	Operating Voltage 350-600 V Unit Nom. Power 3.45 kW AC
Inverter pack	Number of Inverter 4 units Total Power 13.80 kW AC

TABLE 32: PV ARRAY LOSS FACTORS IN SCENARIO 1

Thermal Loss factor	Uc (const) 20.0 W/m²K Uv (wind) 0.0 W/m²K / m/s
Nominal Oper. Coll. Temp.	NOCT 56 °C (G=800 W/m², Tamb=20°C, Wind=1 m/s.)
Wiring Ohmic Loss	Global array res. 257 mOhm Loss Fraction 1.5 % at STC
Module Quality Loss	Loss Fraction 1.5 %
Module Mismatch Losses	Loss Fraction 2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM = 1 - bo (1/cos i - 1) bo Parameter 0.05

With these parameters, the following loss diagram (Figure 31) and performance ratio (Figure 32) over the whole year were obtained.

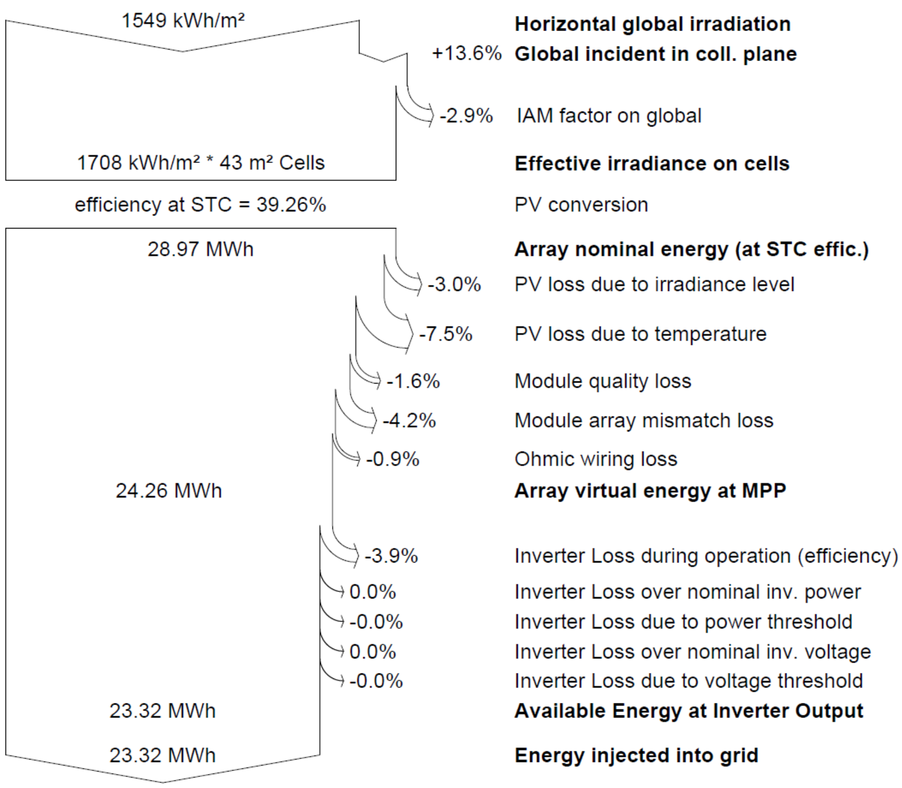


FIGURE 31: LOSS DIAGRAM OVER THE WHOLE YEAR IN SCENARIO 1

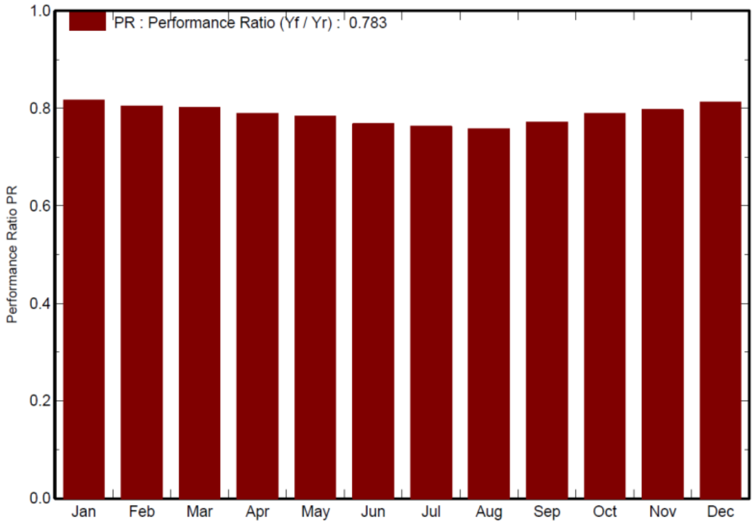


FIGURE 32: PERFORMANCE RATIO PR IN SCENARIO 1

As can be seen in Table 33, this scenario ensures a generation of 23.32 MWh/year, with a specific production of 1,378 kWh/kWp/year and a performance ratio of 78.3 %. Table 34 presents the variation during the whole year of the irradiation, temperature, energy and efficiency.

TABLE 33: MAIN SIMULATION RESULTS IN SCENARIO 1

Produced Energy	23.32 MWh/year
Specific prod.	1,378 kWh/kWp/year
Performance Ratio PR	78.3 %

TABLE 34: BALANCES AND SIMULATION RESULTS IN SCENARIO 1

[2]	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
Jan	61.0	10.00	95.1	92.2	1.367	1.313	12.31	11.83
Feb	73.0	11.00	99.2	96.3	1.408	1.351	12.15	11.67
Mar	129.0	12.50	157.9	153.5	2.227	2.143	12.09	11.63
Apr	140.0	14.00	149.6	145.1	2.080	1.998	11.92	11.44
May	179.0	16.40	176.0	170.7	2.429	2.335	11.83	11.37
Jun	195.0	19.60	183.7	178.1	2.484	2.387	11.59	11.13
Jul	209.0	21.80	199.8	194.0	2.681	2.578	11.49	11.05
Aug	195.0	21.80	203.9	198.1	2.719	2.614	11.42	10.98
Sep	147.0	20.80	173.3	168.4	2.352	2.263	11.63	11.19
Oct	104.0	17.40	137.6	133.6	1.910	1.836	11.89	11.43
Nov	63.0	13.00	93.6	90.7	1.316	1.262	12.04	11.55
Dec	54.0	10.40	89.9	87.1	1.288	1.236	12.28	11.78
Year	**1,549.0**	**15.75**	**1,759.7**	**1,707.9**	**24.260**	**23.317**	**11.81**	**11.35**

[2] GlobHor - Horizontal global irradiation; T Amb - Ambient Temperature; GlobInc - Global incident in coll. Plane; GlobEff - Effective Global, corr. for IAM and shadings; EArray - Effective energy at the output of the array; E_Grid - Energy injected into grid; EffArrR - Effic. Eout array / rough area; EffSysR - Effic. Eout system / rough area

The variation during the year of the normalized generation (per installed kWp) is presented in Figure 33 and the variation of the energy injected into grid is presented in Figure 34.

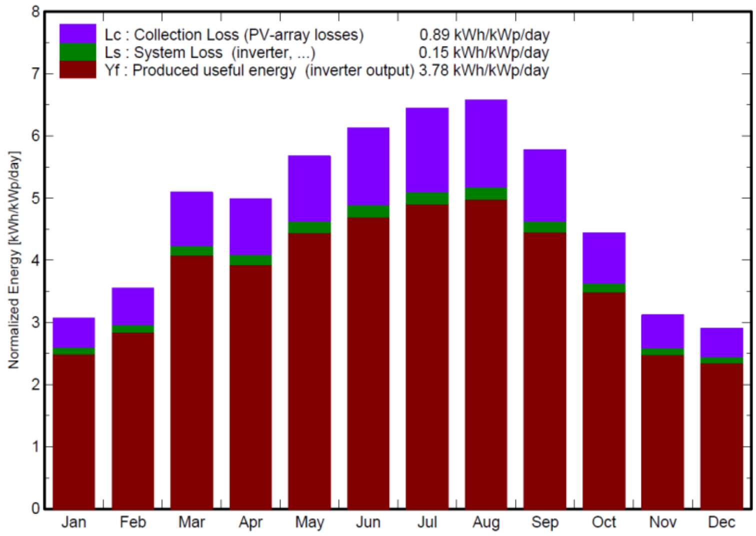


FIGURE 33: NORMALIZED GENERATION (PER INSTALLED KWP) IN SCENARIO 1

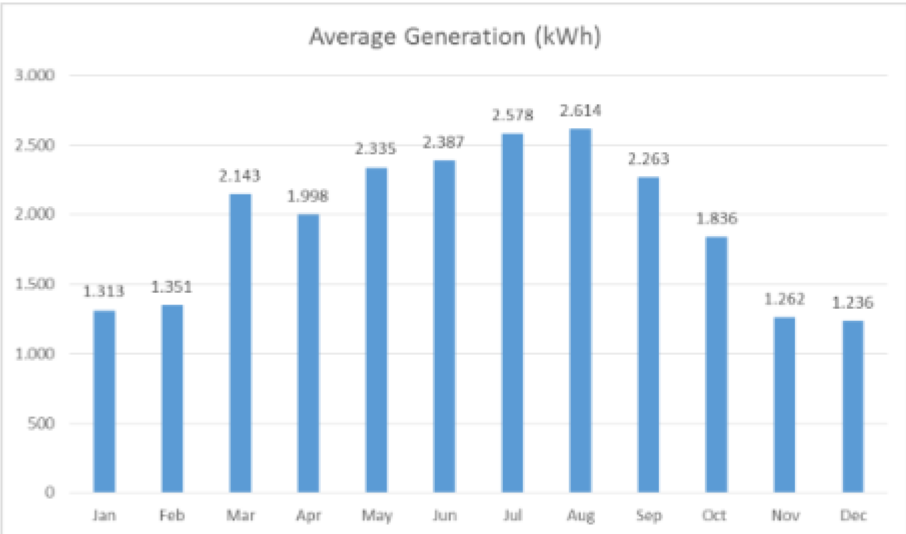


FIGURE 34: ENERGY INJECTED INTO GRID IN SCENARIO 1

In the simulation of scenario 2, it was considered series of 18 modules and 6 strings in parallel. Table 35 presents the PV array characteristics, Table 36 presents the inverter characteristics and Table 37 presents the PV array loss factors.

TABLE 35: PV ARRAY CHARACTERISTICS IN SCENARIO 2

PV module	Si-poly
Model	SINPRIME PREMIUM 235
Manufacturer	SINERGIAE
Number of PV modules	In series 18 modules In parallel 6 strings
Total number of PV modules	108
Unit Nom. Power	235 Wp
Array global power	Nominal (STC) 25.38 kWp At operating cond. 22.81 kWp (50°C)
Array operating characteristics (50°C)	U mpp 485 V I mpp 47 A
Total area	Module area 175 m^2 Cell area 64.8 m^2

TABLE 36: INVERTER CHARACTERISTICS IN SCENARIO 2

Model	Powador 4200
Manufacturer	KACO new energy
Characteristics	Operating Voltage 350-600 V Unit Nom. Power 3.45 kW AC
Inverter pack	Number of Inverter 6 units Total Power 20.70 kW AC

TABLE 37: PV ARRAY LOSS FACTORS IN SCENARIO 2

Thermal Loss factor	Uc (const) 20.0 W/m^2K Uv (wind) 0.0 W/m^2K / m/s
Nominal Oper. Coll. Temp.	NOCT 56 °C (G=800 W/m^2, Tamb=20°C, Wind=1 m/s.)
Wiring Ohmic Loss	Global array res. 171 mOhm Loss Fraction 1.5 % at STC
Module Quality Loss	Loss Fraction 1.5 %
Module Mismatch Losses	Loss Fraction 2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM = 1 - bo (1/cos i - 1) bo Parameter 0.05

With these parameters, the following loss diagram (Figure 35) and performance ratio (Figure 36) over the whole year were obtained.

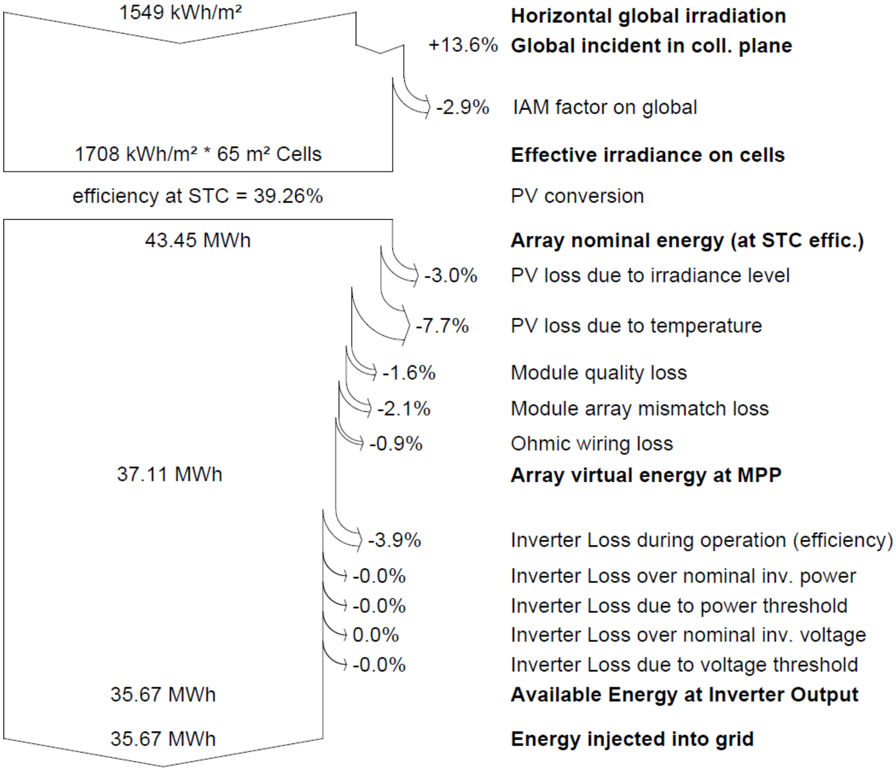


FIGURE 35: LOSS DIAGRAM OVER THE WHOLE YEAR IN SCENARIO 2

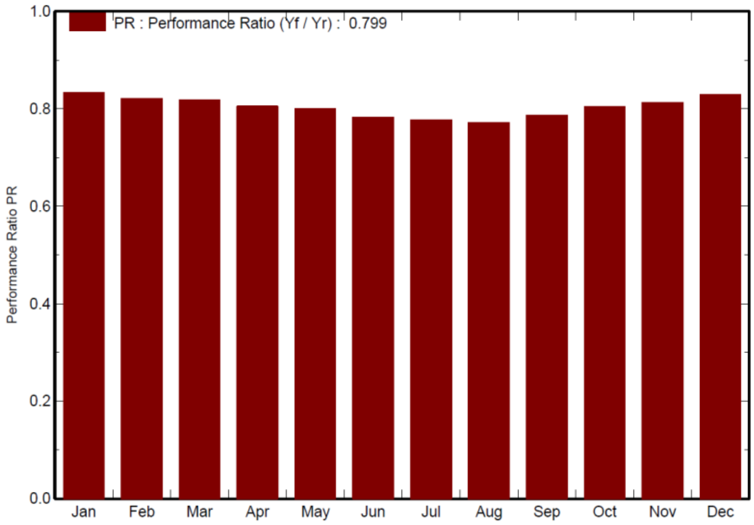


FIGURE 36: PERFORMANCE RATIO PR IN SCENARIO 2

As can be seen in Table 38, this scenario ensures a generation of 35.67 MWh/year, with a specific production of 1,405 kWh/kWp/year and a performance ratio of 79.9 %. Table 39 presents the variation during the whole year of the irradiation, temperature, energy and efficiency.

TABLE 38: MAIN SIMULATION RESULTS IN SCENARIO 2

Produced Energy	35.67 MWh/year
Specific prod.	1,405 kWh/kWp/year
Performance Ratio PR	79.9 %

TABLE 39: BALANCES AND SIMULATION RESULTS IN SCENARIO 2

[3]	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
Jan	61.0	10.00	95.1	92.2	2.093	2.011	12.57	12.07
Feb	73.0	11.00	99.2	96.3	2.155	2.069	12.40	11.91
Mar	129.0	12.50	157.9	153.5	3.406	3.277	12.33	11.86
Apr	140.0	14.00	149.6	145.1	3.182	3.056	12.15	11.67
May	179.0	16.40	176.0	170.7	3.716	3.572	12.06	11.60
Jun	195.0	19.60	183.7	178.1	3.798	3.650	11.81	11.35
Jul	209.0	21.80	199.8	194.0	4.099	3.941	11.71	11.26
Aug	195.0	21.80	203.9	198.1	4.154	3.995	11.64	11.19
Sep	147.0	20.80	173.3	168.4	3.596	3.460	11.85	11.40
Oct	104.0	17.40	137.6	133.6	2.921	2.809	12.12	11.66
Nov	63.0	13.00	93.6	90.7	2.014	1.932	12.29	11.79
Dec	54.0	10.40	89.9	87.1	1.972	1.893	12.53	12.03
Year	**1,549.0**	**15.75**	**1,759.7**	**1707.9**	**37.106**	**35.665**	**12.04**	**11.58**

The variation during the year of the normalized generation (per installed kWp) is presented in Figure 37 and the variation of the energy injected into grid is presented in Figure 38.

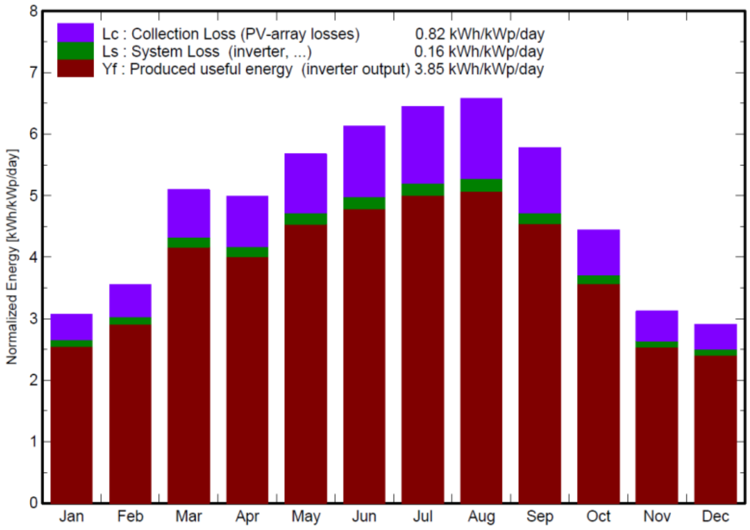


FIGURE 37: NORMALIZED GENERATION (PER INSTALLED KWP) IN SCENARIO 2

[3] GlobHor - Horizontal global irradiation; T Amb - Ambient Temperature; GlobInc - Global incident in coll. Plane; GlobEff - Effective Global, corr. for IAM and shadings; EArray - Effective energy at the output of the array; E_Grid - Energy injected into grid; EffArrR - Effic. Eout array / rough area; EffSysR - Effic. Eout system / rough area

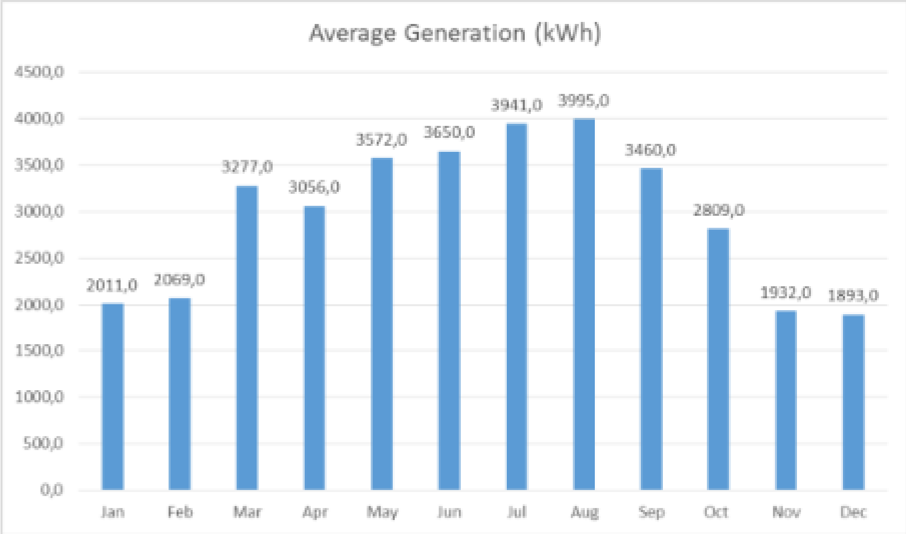


FIGURE 38: ENERGY INJECTED INTO GRID IN SCENARIO 2

Table 40 presents the yearly generation in the 2 scenarios, as well as the percentage of consumption that can be ensured with such generation level. As can be seen, excluding the consumption of the prefabricated building, both scenarios ensure more generation than the actual electricity consumption and scenario 2 ensures almost (90.8%) all the actual energy needs. As presented in detail in section 4.2, it was considered that 10% of the yearly generation has to be inejected into the electrical grid.

TABLE 40: YEARLY GENERATION IN THE 2 SCENARIOS

	Actual 18 panels	Scenario 1 72 panels	Scenario 2 108 panels
Generation (kWh)	6,100.9	23,316	35,665
% Electricity Cons. excl PF	27.1%	103.6%	158.4%
% Electricity Cons. incl. PF	19.8%	75.8%	116.0%
% Energy Cons. excl PF	15.5%	59.3%	90.8%
% Energy Cons. incl. PF	12.8%	49.1%	75.0%

3.4.2. Solar Thermal Collectors

The building already has a solar thermal collector and since the use of hot water is low, its increase was not considered in the renovation plan.

3.4.3. CHP

The building does not have a constant need of heating and therefore the installation of CHP technologies was not considered in the renovation plan.

3.5. Total Impact of the Renovation Scheme

3.5.1. Energy Performance

In the assessment of the total impact the following 5 individual scenarios were considered:

- PV1 – 72 PV panels;
- PV2 – 108 PV panels;
- Light1 – replacement of all T8 lamps with electromagnetic ballast by T5 lamps with electronic ballast;
- Light2 – replacement of all lamps by LEDs.
- HVAC1 – replacement of the gas boiler by a heat pump.

Additionally, it was considered the aggregation of scenarios.

Table 41 presents the achievable yerly savings, as well as the net energy consumption (difference between the energy consumption and generation) in each scenario. The negative values (green) represent situations where the energy generation is higher than the energy consumption.

Table 41: Savings and net energy consumption in several scenarios

Scenario	Savings	Net-consumption			
		Inc. PB		Exc. PB	
Baseline	0 kWh	47,504 kWh	100%	39,219 kWh	100%
PV1	23,316	24,188	50.9%	15,903	40.5%
PV2	35,665	11,839	24.9%	3,554	9.1%
Light1	3,099	44,405	93.5%	36,120	92.1%
Light2	5,730	41,774	87.9%	33,489	85.4%
HVAC1	11,876	35,628	75.0%	27,343	69.7%
PV1+Light1	26,415	21,089	44.4%	12,804	32.6%
PV1+Light2	29,046	18,458	38.9%	10,173	25.9%
PV2+Light1	38,764	8,740	18.4%	455	1.2%
PV2+Light2	41,395	6,109	12.9%	-2,176	-5.5%
PV1+HVAC1	35,192	12,312	25.9%	4,027	10.3%
PV2+HVAC1	47,541	-37	-0.1%	-8,322	-21.2%
PV1+Light1+HVAC1	38,291	9,213	19.4%	928	2.4%
PV1+Light2+HVAC1	40,922	6,582	13.9%	-1,703	-4.3%
PV2+Light1+HVAC1	50,640	-3,136	-6.6%	-11,421	-29.1%
PV2+Light2+HVAC1	53,271	-5,767	-12.1%	-14,052	-35.8%

As can be seen, there are several scenarios ensuring a negative net energy consumption (scenarios PV2+Light2, PV2+HVAC1, PV1+Light2+HVAC1, PV2+Light1+HVAC1, PV2+Light2+HVAC1), even including the consumption of the prefabricated building (scenarios PV2+HVAC1, PV2+Light1+HVAC1, PV2+Light2+HVAC1). However, several scenarios result in negative net energy consumption, i.e. more PV-production than needed, since the ideal is to have almost zero net energy consumption in order to avoid unnecessary investments.

The scenarios that are more near to achieve a zero net energy consumption, despite presenting a slightly positive net energy consumption, are scenarios PV2+Light1 (1.2%) and PV1+Light1+HVAC1 (2,4%). Scenario PV1+Light1+HVAC1 has a good balance between the increase of PV generation level and the increase of efficiency in the 2 main systems (lighting and HVAC) and is therefore the best solution for achieve a Zero Energy Building.

The selected scenario is constituted by:

- Increase the PV system to 72 PV panels;
- Replacement of all T8 lamps with electromagnetic ballast by T5 lamps with electronic ballast;
- Replacement of the gas boiler by a heat pump.

3.5.2. Environmental Performance

As can be seen in Table 42, with the renovation 96.2% of the consumed energy is ensured by renewable energy sources, therefore achieving the aim of 95% renewable energy sources.

TABLE 42: RENEWABLE GENERATION SHARE

	Energy Consumption kWh	Energy Generation kWh	Energy Generation %
Renovation	24,244	23,316	96.2%

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

- electricity to primary energy - 2.5 (standard value approved for Portugal);
- natural gas to primary energy - 1.0 (standard value);
- electricity to CO_2 emissions - 139.89 g/kWh (average emissions associated with the electricity consumed in Portugal during 2013);
- natural gas to CO_2 emissions - 202 g/kWh (standard value).

As can be seen in Table 43, the renovation plan can ensure 97.6% savings in final energy, 96.8% savings in primary energy and 98.0% savings in CO_2 emissions, therefore achieving the aim of 95% of primary energy reduction.

TABLE 43: FINAL ENERGY, PRIMARY ENERGY AND CO_2 EMISSIONS SAVINGS

	Final Energy kWh	Energy Dens. kWh/m^2	Primary Energy kWh	CO_2 Emissions kg CO_2 /kWh
Electricity base.	22,516	13.60	56,290	3,149.8
Gas base.	16,775	10.14	16,775	3,388.6
Total base.	39,291	23.74	73,065	6,538.3
Electricity renov.	928	0.56	2,320	129.8
Gas renov.	0	0	0	0
Total renov.	928	0.56	2,320	129.8
Savings	38,363	23.18	70,745	6,408.5
Savings (%)	97.6%	97.6%	96.8%	98.0%

4. Economic Evaluation of the Proposed Renovation Scheme

4.1. Assumptions and Cost Figures

The costs of the selected renovation options were determined by consulting catalogues and installers and considering a typical reduction of costs due to the quantity.

Table 44 presents the considered costs for the following renovation options:

- Installation of 12.69 kWp of PV panels (54 panels);
- Installation of 143 T5 lamps and luminaries with electronic ballast;
- Installation of heat pump with 11 kW to replace a gas boiler.

TABLE 44: COSTS OF THE SELECTED RENOVATION OPTIONS

Renovation Option	Equipment €	Installation €	Total €
PV	16,922	5,071	21,993
Lighting	2,205	715	2,920
HVAC	5,306	1,250	6,556
Total	**24,433**	**7,036**	**31,469**

Table 45 presents the actual tariffs of the consumed electricity in the building, disaggregated by period.

TABLE 45: ELECTRICITY TARIFFS

Period	Energy €/kWh	Taxes €/kWh	Total €/kWh
On-Peak	0.2938	0.0686	0.3624
Mid-Peak	0.1477	0.0350	0.1827
Off-Peak	0.0845	0.0204	0.1049

Considering the actual distribution of the consumption between periods, the average costs were obtained using 2 scenarios (Table 46): considering just the daylight hours (to be used in the evaluation of PV generation) and considering all the periods.

TABLE 46: AVERAGE COST OF THE CONSUMED ELECTRICITYY

<table>
<tr><th>Period</th><th>Cost
€/kWh</th><th>Consumption
%</th><th>Day
€/kWh</th><th>Total
€/kWh</th></tr>
<tr><td>On-Peak</td><td>0.3624</td><td>18.4%</td><td rowspan="2">0.2260</td><td rowspan="3">0.1974</td></tr>
<tr><td>Mid-Peak</td><td>0.1827</td><td>58.0%</td></tr>
<tr><td>Off-Peak</td><td>0.1049</td><td>23.6%</td><td></td></tr>
</table>

4.2. Results

In the evaluation of the PV generation it was considered the self-consumption of 90% of the energy, since in a working day during the period of classes, the additional consumption of the pre-fabricated building ensures that all the generation can be consumed locally. The exceptions are the weekends and periods without classes, since the consumption is low and therefore part of the energy should be injected into grid. In the economic evaluation, the self-consumption was considered to avoid the average cost of energy during the daylight hours (0.2260 €/kWh), the energy injected into the grid, with the new Portuguese regulation for self-consumption, is paid with 90% of the average cost of the electricity in the Electricity Market during the correspondent month (it was considered as 0.05 €/kWh). As can be seen in Table 47, with such conditions the renovation options ensures savings of 3,588 €/year and has a simple payback period of 6.1 years.

TABLE 47: ECONOMIC PARAMETERS OF THE RENOVATION – PV GENERATION

Energy Generation	17,216 kWh
Energy - Self-Consumption	90%
Energy - Injected Into Grid	10%
Price – Self-Consumption	0.2260 €/kWh
Price - Injected Into Grid	0.05 €/kWh
Costs	21,993 €
Savings	3,588 €/year
Simple Payback	6.1 years
Lifetime	30 years
CO_2 Savings	2.41 tons/year

In the evaluation of the lighting savings it was considered the average cost of the electricity. The lifetime was assessed considering the average hours of use for the lamps and its maximum total hours of operation. As can be seen in Table 48, with such conditions the renovation options ensures savings of 612 €/year and has a simple payback period of 4.8 years.

TABLE 48: ECONOMIC PARAMETERS OF THE RENOVATION – LIGHTING

Energy Savings	3,099 kWh
Price - Saved Energy	0,1974 €/kWh
Costs	2,920 €
Savings	612 €/year
Simple Payback	4.8 years
Lifetime	13 years
CO_2 Savings	0.43 tons/year

In the evaluation of the HVAC savings it was considered the cost of the electricity during the mid-peak period (the period of operation matches such period) and the saving of the actual natural gas costs. As can be seen in Table 49, with such conditions the renovation options ensures savings of 882 €/year and has a simple payback period of 7.4 years.

TABLE 49: ECONOMIC PARAMETERS OF THE RENOVATION – HVAC

Energy Savings	11,876 kWh
Gas Costs (before)	1,778 €
Price - Electricity	0.1827 €/kWh
Electricity Costs (after)	896 €
Costs	6,556 €
Savings	882 €/year
Simple Payback	7.4 years
Lifetime	20 years
CO_2 Savings	2.70 tons/year

Table 50 presents the aggregation of the renovation option. As can be seen, the total of the renovation plan ensures savings of 5,082 €/year and has a simple payback period of 6.19 years.

TABLE 50: ECONOMIC PARAMETERS OF THE RENOVATION – TOTAL

Energy Savings	32,191 kWh
Costs	31,469 €
Savings	5,082 €/year
Simple Payback	6.19 years
CO_2 Savings	5.54 tons/year

B. Municipal House of Culture

5. Building General Description

5.1. Location

The Municipal House of Culture was built in 1991-1993 and opened on October, 26th 1993. Figure 39 presents the front façade of the building.

FIGURE 39: MUNICIPAL HOUSE OF CULTURE

The building is located near to the city centre and near to the University. Table 51 presents the main location data of the building. Figure 40 and Figure 41 present the location in the city map and aerial view.

TABLE 51: LOCATION DATA OF THE BUILDING

Address	Casa Municipal da Cultura, Rua Pedro Monteiro, 3000-329 Coimbra, Portugal
Coordinates	40.209459, -8.415705
Google Maps	www.google.pt/maps/@40.2092665,-8.4153245,171m/data=!3m1!1e3

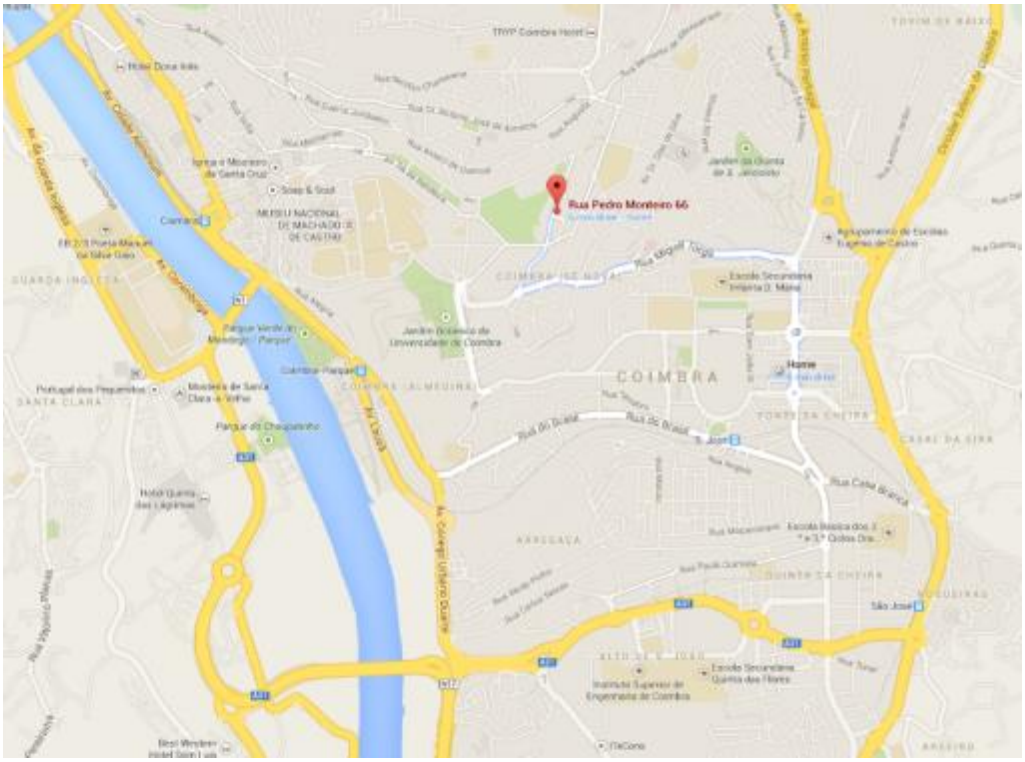


FIGURE 40: LOCATION IN THE CITY (MAP)

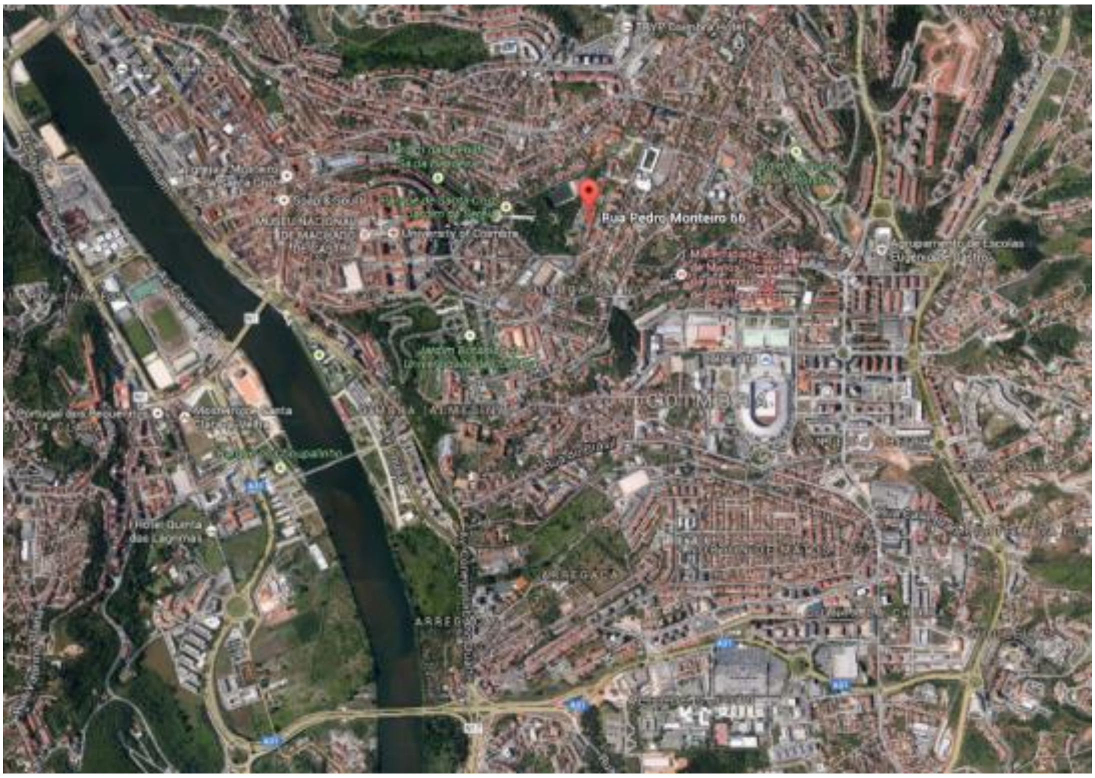


FIGURE 41: LOCATION IN THE CITY (AERIAL VIEW)

5.2. Shape and Orientation

Figure 42 presents the plan view and Figure 45 presents the aerial view of the building. The building has dimensions variable between different floors, presenting a maximum dimensions of 42.05 m x 85.20 m.

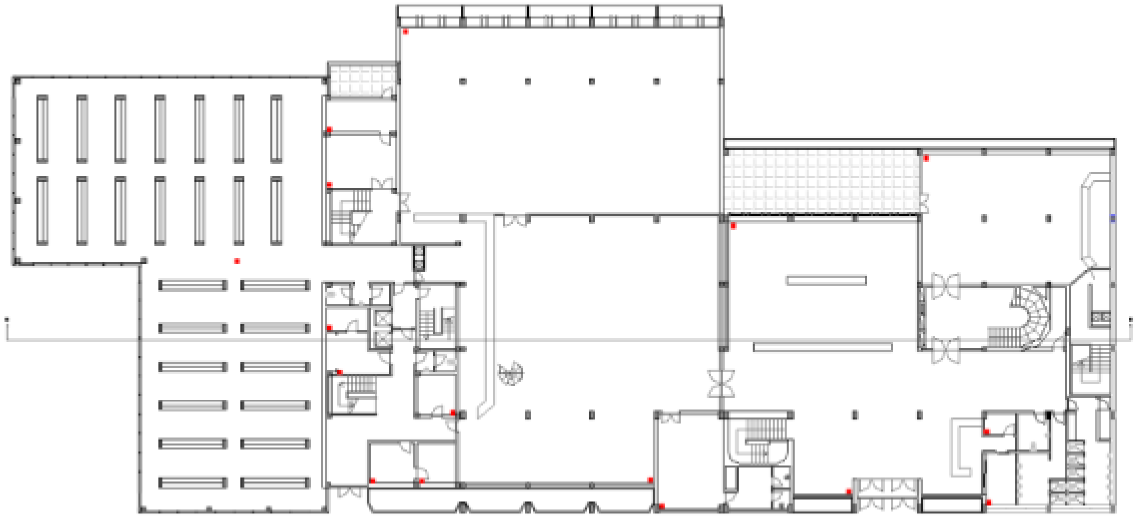


FIGURE 42: PLAN VIEW

Figure 43 presents the cross section of the building, which has 8 floors, with 3 floors below and 4 floors above the ground floor and Figure 44 presents the elevation plan.

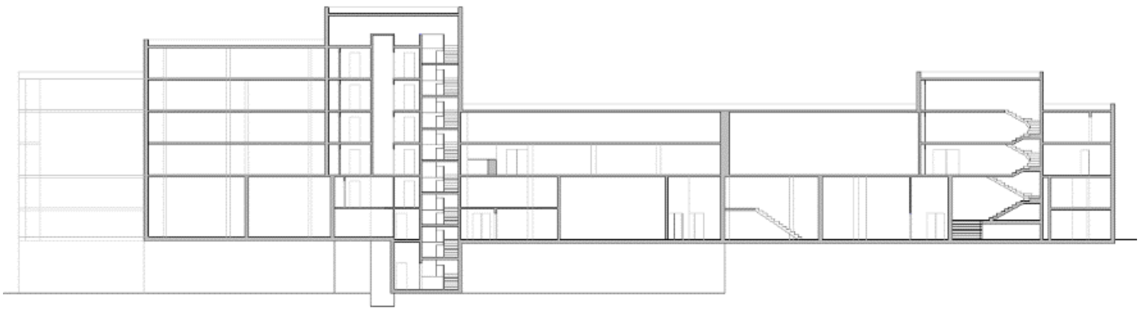


FIGURE 43: CROSS SECTION

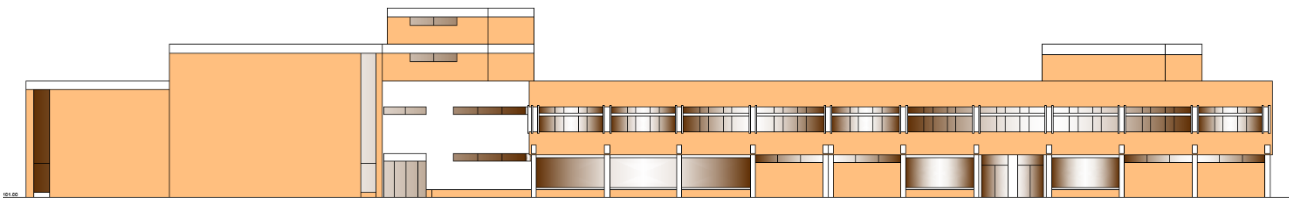


FIGURE 44: ELEVATION PLAN

FIGURE 45: AERIAL VIEW

As can be seen in Figure 46 the building is oriented with an axis of 200º, with the main façade oriented to East.

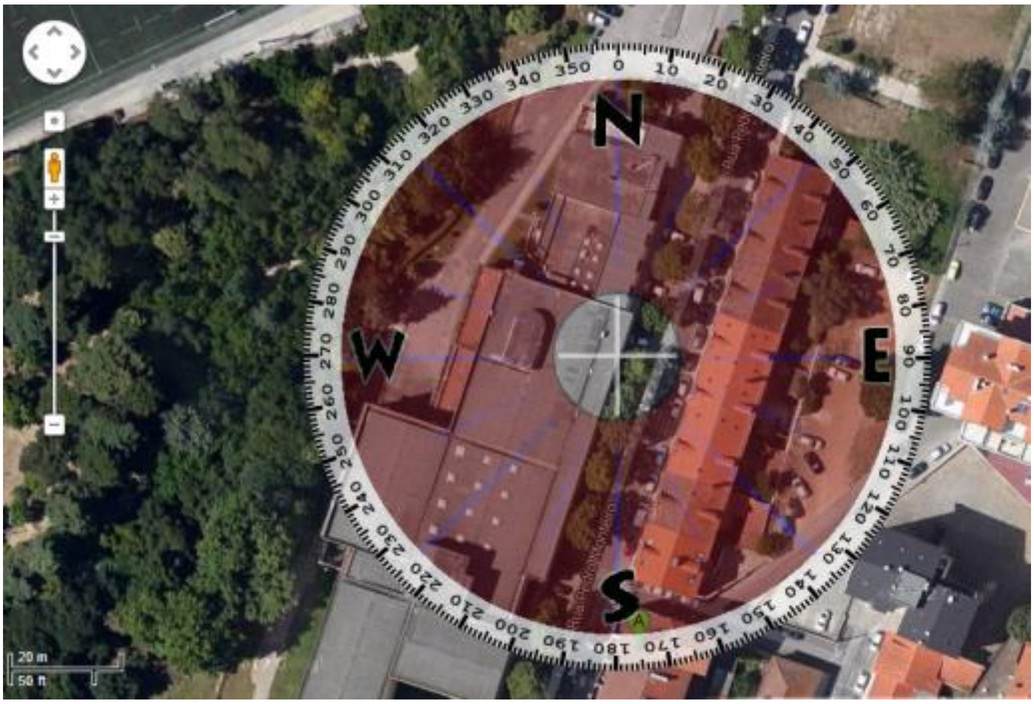


FIGURE 46: ORIENTATION OF THE MAIN FAÇADE

5.3. Area and Volume

The building has total area of about 13,225 m^2 with a total used surface of about 9,862 m^2 and a volume of 39,944 m^3.

As can be seen in Figure 5 the roof is flat without tiles and has a surface of 2,565 m^2. The roof is now constituted by asbestos-cement slabs. However, it will soon be replaced by a sandwich panel constituted by two thermolacquered metal sheets with 80 mm of polyurethane insulation.

5.4. Current Use

The building is the Municipal House of Culture and has several cultural equipment, such as library, auditorium and art gallery.

There are two areas of the building loaned to other entities:

- Part of floor -2 is one refectory used by the University of Coimbra;
- Part of floor -3 is used by the CAPC - *Círculo de Artes Plásticas de Coimbra* (cultural association of contemporary art).

These spaces are managed by such entities, but they receive electricity from the main board of the building, being the electricity paid by the Municipality.

Table 52 presents the several rooms (identified in Figure 47 to Figure 54) and the respective use.

The building has 80 employees and is visited by 17,500 users/year and works with the following schedule.

July 15th to September 15th:

- Monday to Friday: 9h00 – 18h30

September 16th to July 14th:

- Monday to Friday: 9h00 – 19h30
- Saturday: 11h00 – 13h00 and 14h00 and 19h00

The users have access to the rooms of public use only after 10h00.

The refectory works between 8h30 and 17h00 (Monday to Friday), with the lunches served between 12h00 and 15h00. In the periods 09h00-11h00 and 12h00-16h45 the refectory works as cafeteria. The refectory is closed during August and during the Christmas and Easter holidays.

The CAPC has not had any regular activity.

TABLE 52: USE OF THE DIFFERENT ROOMS

Room	Floor	Use	Room	Floor	Use
1	4	Engine room - Lift	66	0	WC
2	3	Silo	67	0	WC
3	3	Storage	68	0	Office
4	3	Storage	69	0	Office
5	3	Storage	70	-1	Silo
6	3	WC	71	-1	Carpentry
7	3	Hall	72	-1	Carpentry
8	3	Office	73	-1	Storage
9	2	Silo	74	-1	Hall
10	2	Storage	75	-1	WC
11	2	Storage	76	-1	Office
12	2	Storage	77	-1	Office
13	2	Hall	78	-1	Hall
14	2	Hall	79	-1	Hall
15	2	Hall	80	-1	Hall
16	2	Office	81	-1	Storage
17	1	Silo	82	-1	Storage
18	1	Office	83	-1	Storage
19	1	Image Library	84	-1	Storage
20	1	WC	85	-2	Silo
21	1	Storage	86	-2	Museography
22	1	Storage	87	-2	Museography
23	1	Hall	88	-2	Carpentry
24	1	Hall	89	-2	Carpentry
25	1	Cataloguing Room	90	-2	Storage
26	1	WC	91	-2	Storage
27	1	WC	92	-2	Storage
28	1	Hall	93	-2	Hall
29	1	Reading Service - Visually Impaired	94	-2	Storage
30	1	Office	95	-2	Municipal Archive
31	1	Cataloguing Room of Monographs	96	-2	Toy Library
32	1	Librarians Room	97	-2	Toy Library
33	1	Catalogue of Periodicals	98	-2	Hall
34	1	Office	99	-2	WC
35	1	Office	100	-2	WC
36	1	Office	101	-2	WC
37	1	Room Francisco Miranda de Sá	102	-2	Office
38	1	Storage	103	-2	WC
39	1	Cultural Action Division	104	-2	Theatre Room
40	1	Hall	105	-2	Storage

41	1	Gallery Armando Carneiro da Silva
42	1	Hall
43	0	Silo
44	0	Old Books Room
45	0	Old Books Room
46	0	Hall
47	0	WC
48	0	Server Room
49	0	Server Room
50	0	Hall
51	0	WC
52	0	Hall
53	0	Office
54	0	Office
55	0	Office
56	0	Library
57	0	Reading Room
58	0	Historical Office José Pinto Lourenço
59	0	WC
60	0	Reception
61	0	Exhibition Hall
62	0	Audio Library
63	0	Hall
64	0	Hall
65	0	WC

106	-2	Atelier
107	-2	Office
108	-2	Gallery Ferrer Correia
109	-2	Multipurpose Room
110	-2	Hall
111	-2	Storage
112	-2	Storage
113	-2	Refectory
114	-2	Storage
115	-2	Feeder
116	-2	Kitchen
117	-2	Washing area
118	-2	Dining Room
119	-2	Food Store
120	-2	Food Store
121	-2	Technical Area of the Theatre
122	-3	Image Library
123	-3	Storage
124	-3	Storage
125	-3	Storage
126	-3	Storage
127	-3	WC
128	-3	Hall
129	-3	CAPC

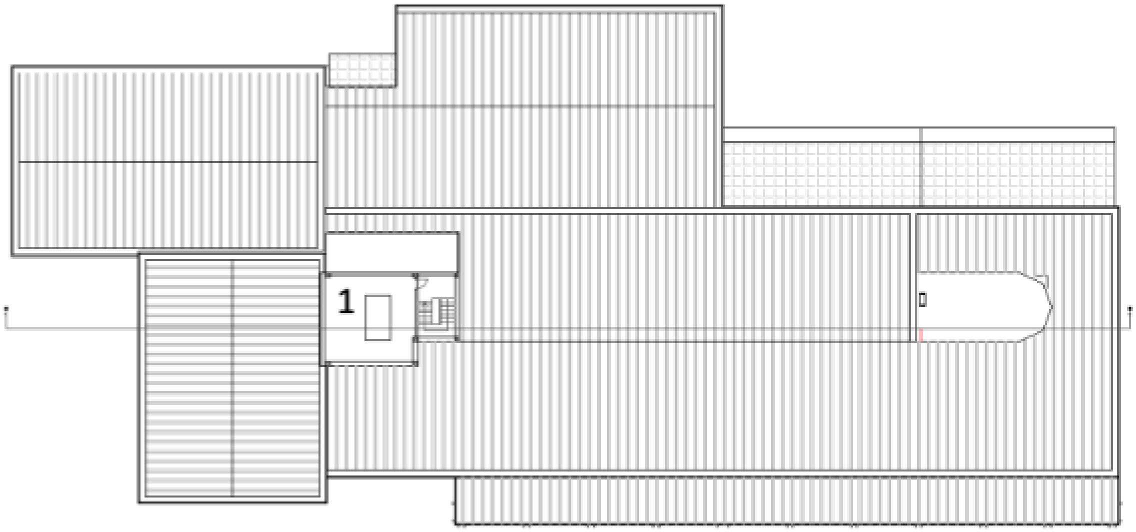


FIGURE 47: ROOMS USE IN FLOOR 4

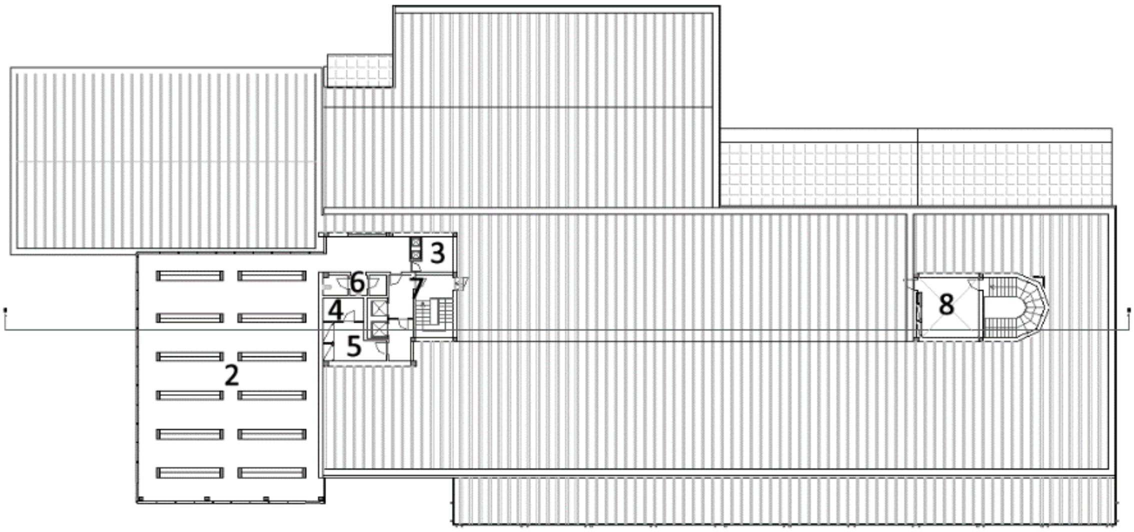


FIGURE 48: ROOMS USE IN FLOOR 3

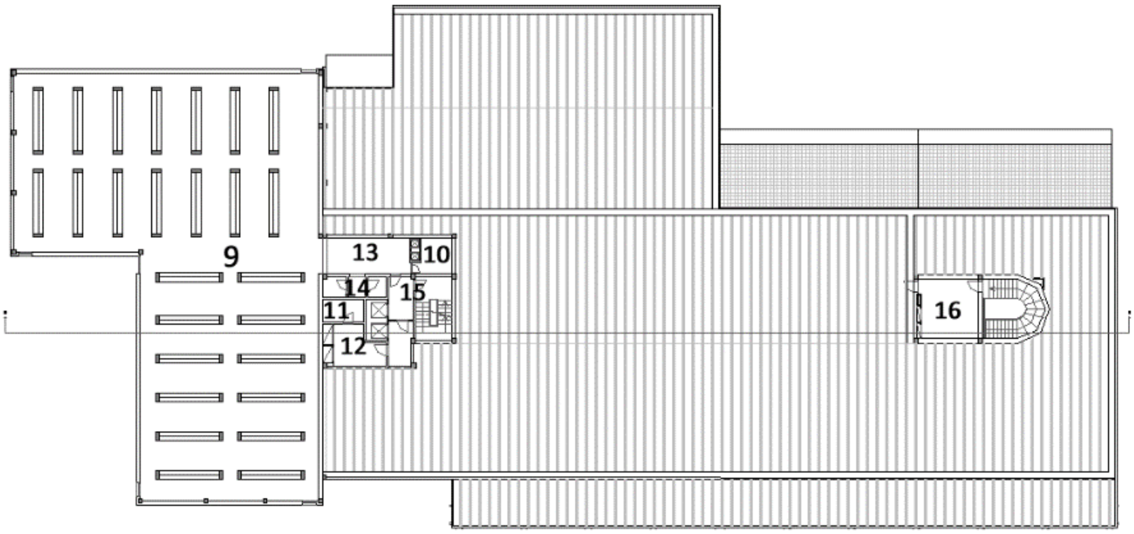


FIGURE 49: ROOMS USE IN FLOOR 2

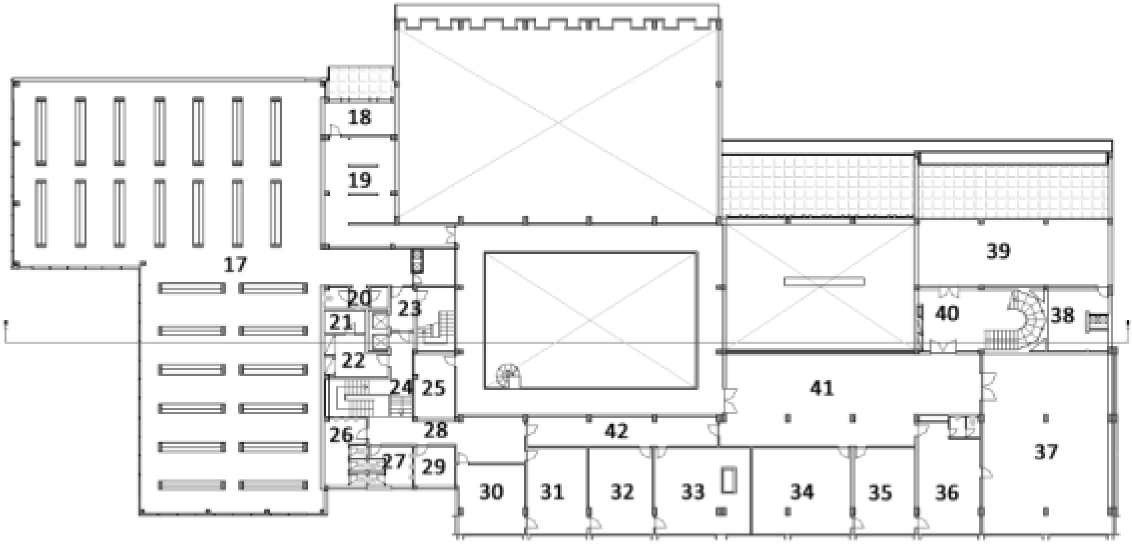


FIGURE 50: ROOMS USE IN FLOOR 1

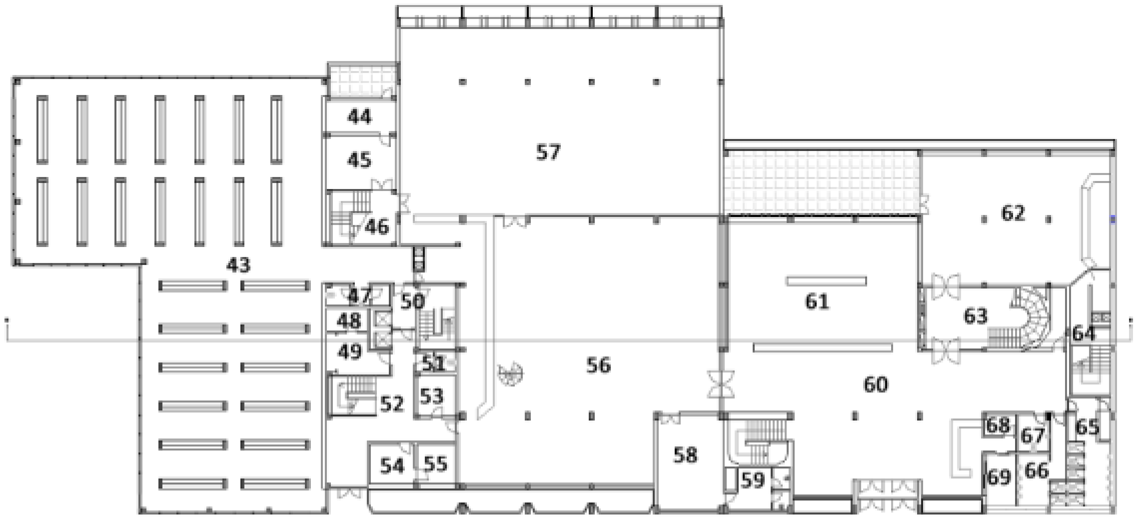


FIGURE 51: ROOMS USE IN FLOOR 0

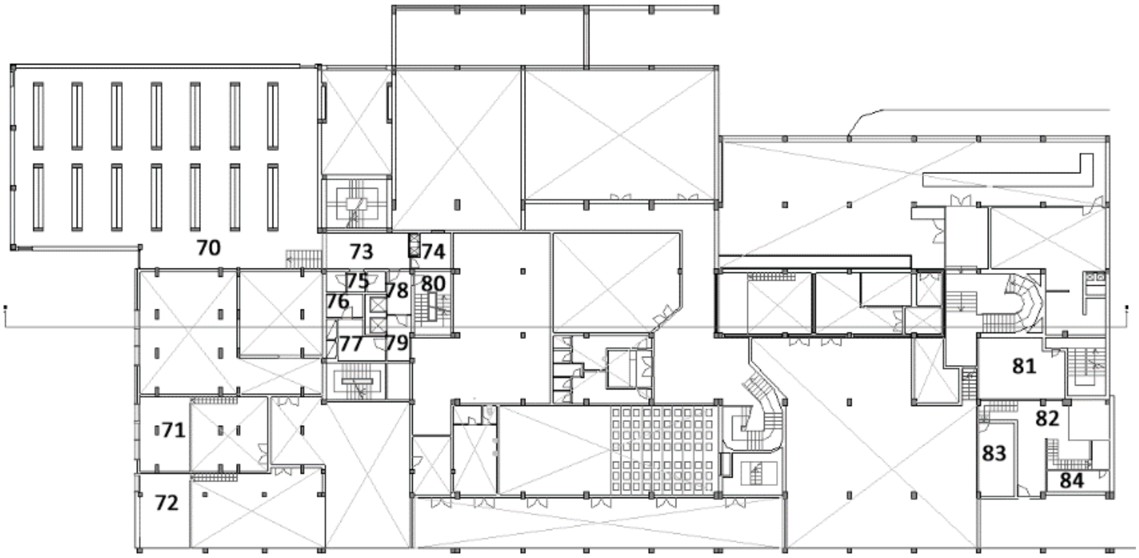


FIGURE 52: ROOMS USE IN FLOOR -1

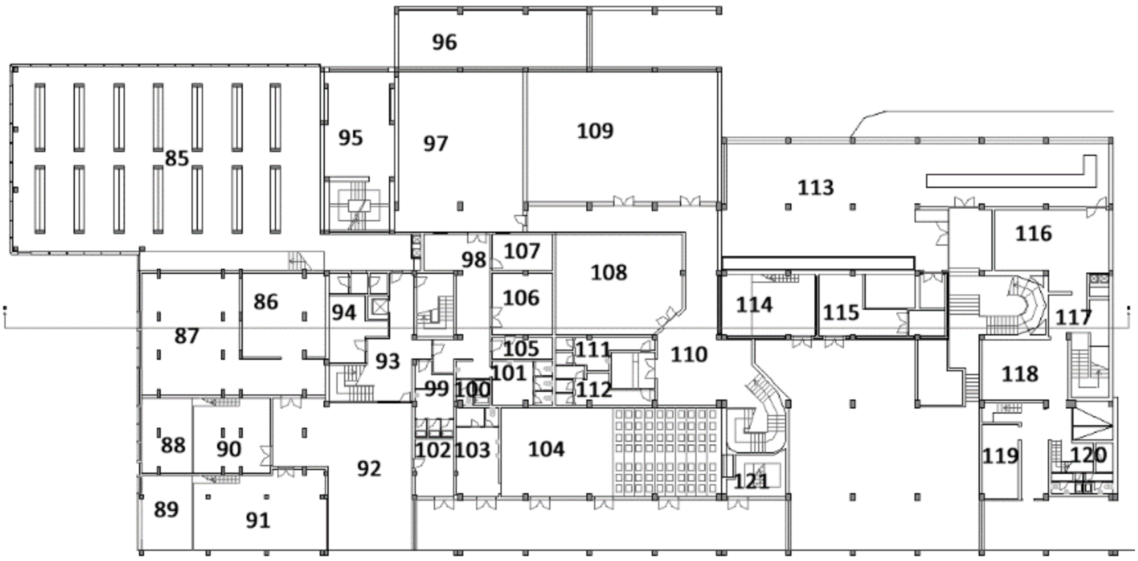


FIGURE 53: ROOMS USE IN FLOOR -2

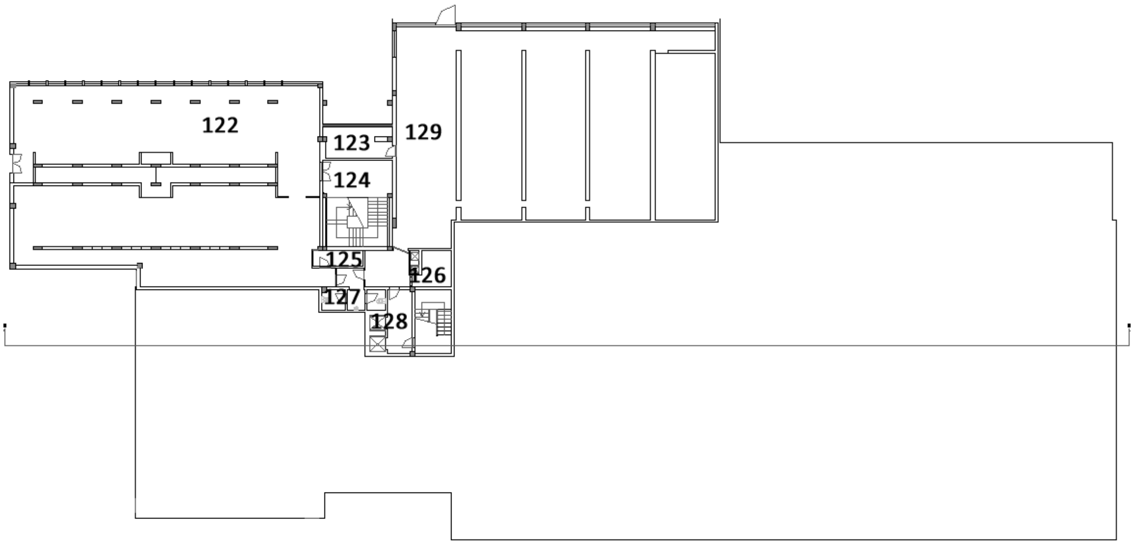


FIGURE 54: ROOMS USE IN FLOOR -3

6. Current Building Conditions

6.1. Constructive Building Characteristics

6.1.1. Envelope Elements

The walls of the front have a total surface of 800 m^2 of which 184 m^2 is transparent (22.9%), the back walls have a total surface of 1,415 m^2, of which 610 m^2 is transparent (43.1%) and the lateral south walls have a total surface of 343 m^2, of which 50 m^2 is transparent (14.6%). The lateral North just have a small window, since it is connected with other building.

The external walls are made of breeze blocks and bricks and have a thickness of 20 to 55 cm.

Table 53 presents the considered heat loss for transmission to the outside in the envelope.

TABLE 53: HEAT LOSS FOR TRANSMISSION TO THE OUTSIDE IN THE ENVELOPE

Structure	Orient.	A	U	Abs.	A.U.A.Rse	U.A.
		m^2	W/m^2 ºC	α	W/ ºC	W/ ºC
Wall - Back	NW	1,415	0.29	0.6	9.85	410.4
Wall - Lateral	SW	343	0.29	0.6	2.39	99.5
Wall - Front	SE	800	0.29	0.6	5.57	232.0
Wall - Lateral	NW	10	0.29	0.6	0.07	2.9
Roof	-	2,565	0.5	0.4	20.52	1282.5

6.1.2. Windows

All the windows are of single glazing with aluminium frames. The doors have the same characteristics of the windows and therefore they were grouped.

In the front there are the following windows/doors:

- 12 operable of 1.55 x 0.50 m
- 2 operable of 1.45 x 0.50 m
- 6 operable of 1.67 x 0.60 m
- 4 operable of 1.6 x 0.60 m
- 10 operable of 4.4 x 1.70 m
- 5 fixed of 4.7 x 2.2 m
- 1 fixed of 1.06 x 9.55 m
- 1 fixed of 1.10 x 7.05 m
- 1 door of 4.25 x 2.90 m
- 1 door of 2.90 x 2.50 m

In the back there are the following windows/doors:

- 1 operable of 4.75 x 1.50 m
- 1 operable of 4.75 x 1.80 m
- 2 operable of 4.75 x 2.20 m
- 1 operable of 25.00 x 3.30 m
- 1 operable of 4.65 x 2.20 m

- 12 operable of 4.65 x 1.90 m
- 4 operable of 1.60 x 0.60 m
- 6 fixed of 4.65 x 4.65 m (one of the windows includes a door)
- 4 fixed of 4.95 x 1.95 m
- 1 fixed of 21.40 x 2.80 m
- 5 fixed of 4.65 x 3.30 m
- 2 fixed of 0.80 x 2.44 m
- 3 fixed of 0.80 x 2.34 m
- 1 fixed of 0.80 x 2.24 m
- 1 door of 4.60 x 2.90 m

In the lateral South there are the following windows/doors:

- 1 fixed of 1.10 x 12.50 m
- 1 fixed of 1.10 x 10.00 m
- 1 fixed of 1.10 x 7.50 m
- 1 fixed of 1.10 x 1.10 m
- 1 fixed of 3.30 x 1.10 m
- 1 door of 2.90 x 2.50 m
- 1 door of 2.80 x 1.80 m

In the lateral North there is only a fixed window of 1.70 x 1.10 m.

Almost all the windows have interior shutters (Figure 55). The exceptions is the front of floor 0 where darkened windows are used.

Some shading is also ensured by other buildings (front and laterals) and trees (front and back).

FIGURE 55: WINDOWS WITH SHUTTERS

Table 54 presents the considered heat loss for transmission to the outside in windows.

TABLE 54: HEAT LOSS FOR TRANSMISSION TO THE OUTSIDE IN WINDOWS

Structure	Orient.	A	U	F_g	A_{eq}	U.A.
		m^2	$W/m^2 ºC$		m^2	W/ ºC
Windows - Back	NW	610	5.7	0.84	512.4	3,477.0
Windows - Lateral	SW	50	5.7	0.84	42.0	285.0
Windows - Front	SE	184	5.7	0.84	154.6	1,048.8

6.1.3. Airtightness and Pathologies

The building does not present major airflows.

On the back façade there are condensations, mainly in areas covered with vegetation (Figure 56).

FIGURE 56: CONDENSATIONS FOUND ON THE BACK FAÇADE

6.2. Energy Systems

6.2.1. Lighting

The lighting is usually ensured by fluorescent lamps. Most of the rooms have a false roof in wood with small square holes, being the luminaries installed above the false roof (Figure 57). The lighting fixtures are open luminaires with double reflector and have 2 or 3 lamps. The installation of the lamps above the false roof causes a high loss of luminosity, which is aggravated by the difficulty of maintenance of such luminaries, being very common to find faulty lamps. These situations lead to a low visibility in some areas.

FIGURE 57: SOME EXAMPLES OF THE LAMPS INSTALLED IN AREAS WITH FALSE ROOF

In the rooms without false roof, such as offices and circulation areas there are several types of luminaires (Figure 58 and Figure 59). In the silos and storage areas, the lighting fixtures are usually open luminaires without reflector.

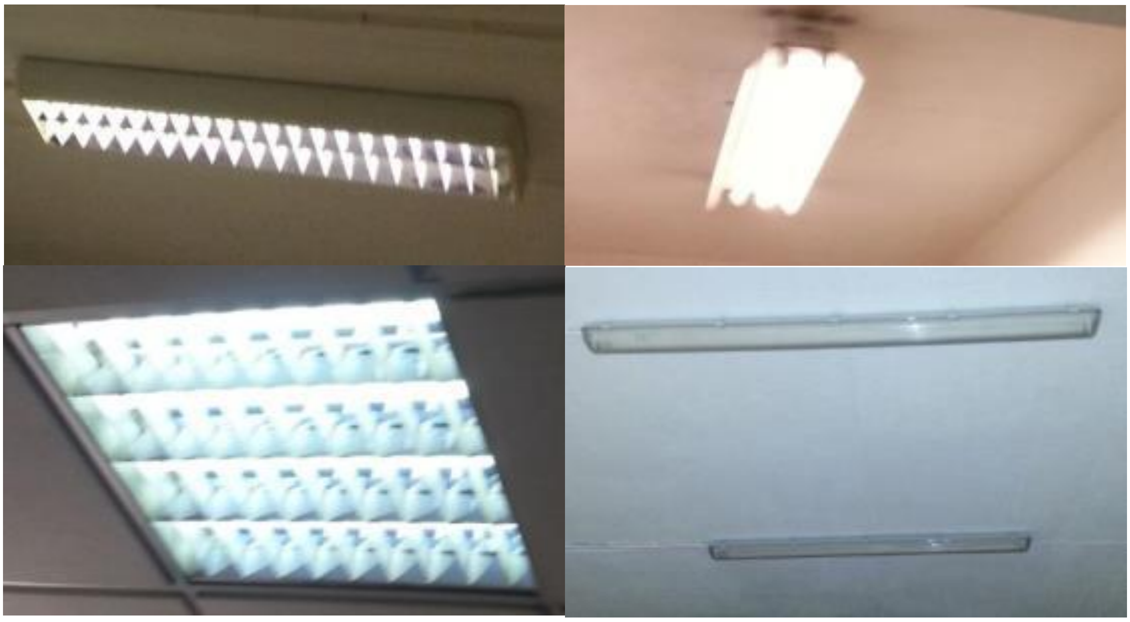


FIGURE 58: SOME EXAMPLES OF THE LAMPS INSTALLED IN AREAS WITHOUT FALSE ROOF

FIGURE 59: LAMPS INSTALLED IN THE TOY LIBRARY

In the circulation areas the lamps are usually of 18 W and in the remaining areas are of 58 W. Almost all the lamps are T8 with ferromagnetic ballasts. The exception is just one circulation area where T5 lamps with electronic ballasts (stairs of area 52 – floor 0 to -2) are already used.

Some rooms with double height ceiling use incandescent and halogen lamps (Figure 60 and Figure 61).

FIGURE 60: LAMPS INSTALLED IN THE MULTIPURPOSE ROOM

FIGURE 61: LAMPS INSTALLED IN STORAGE AREAS

The bathrooms had incandescent lamps. However, some lamps were already replaced by CFL and one bathroom (near to the reception on floor 0), recently renovated, already have LED lamps (Figure 62).

FIGURE 62: LED LAMPS INSTALLED IN ONE BATHROOM

The control of the lighting in the circulation areas, bathrooms and rooms receiving public is directly ensured in the electrical board. This is a major problem in circulation areas, since areas with reduced utilization (in parts of the building not receiving public) have the lightning permanently turned ON during the working hours. In offices and other rooms the control is ensured locally by switches/commutators.

Table 55 presents the types and quantities of lamps, as well as the total installed power.

TABLE 55: TYPES AND QUANTITIES OF LAMPS

Lamp Type	Quantity n	Power W
Fluorescent Linear T8 F60	9	211
Fluorescent Linear T8 F120	803	37,580
Fluorescent Linear T8 F150	312	21,091
Fluorescent Linear T5 F60	8	136
Incandescent	23	1,380
Halogen Projector	24	7,200
Halogen Spot	5	250
Compact Fluorescent	70	1,260
LED Spot	12	66
Total	**1,266**	**69,174**

6.2.2. HVAC

Almost all working rooms, as well as all the rooms receiving have acclimatization. The circulation areas do not have acclimatization. The total acclimatized area is about 6,900 m^2.

The building does not have a centralized HVAC system. It has several mono-split units, which were gradually installed. The exception to it, are the silos / storage areas which have systems (one in each silo) of temperature and humidity control with pipelines to protect the publications.

The total number of HVAC devices is:

- 9 systems of temperature and humidity control with pipelines with a total power of 301 kW (Figure 63);
- 36 mono-split systems with heat pumps installed in the wall or roof with a total power of 239.27 kW (Figure 64).

FIGURE 63: SYSTEMS OF TEMPERATURE AND HUMIDITY CONTROL

FIGURE 64: EXAMPLES OF MONO-SPLIT HVAC SYSTEMS

The system of temperature and humidity control uses units CIATESA ISW-120 (Table 56).

TABLE 56: TECHNICAL DATA OF THE CIATESA ISW-120

$P_{cooling-ther}$ (kW)	$P_{cooling-elect}$ (kW)	EER[4]	$P_{heating-ther}$ (kW)	$P_{heating-elect}$ (kW)	COP[5]	$P_{compressor}$ (kW)	$P_{ventilator}$ (kW)
29.7	12.2	2.43	30.3	10.2	2.97	7.5	1.1

[4] Energy Efficiency Ratio
[5] Coefficient Of Performance

The control of the temperature and humidity control systems is ensured in an electrical board near to each system. The control of the split systems in directly ensured in the device or using an infrared remote control. All the split systems are mono-split (each machine has one compressor) and they receive electricity from different electrical boards dispersed throughout the building. The bathrooms in floor 0 (areas 65 and 66) have ventilation which is permanently connected.

It was detected that 4 of the 9 systems of temperature and humidity control are not working (the employees working in the library do not know the reason to it). These systems control the conditions in the silos situated in the front of the building.

The total power of the HVAC systems is 540.27 kW.

6.2.3. ICT

It was considered as ICT (Information and Communications Technologies) not only the communication devices but also other electronic devices, such as computers, printers, etc. Most of the offices and rooms have computers and printers and there is a room with servers and an internal circuit of CCTV for security.

There are photocopier machines and video projectors in some rooms.

6.2.4. Others

The cooking equipment is just used in the University refectory. Since this space is not managed by the Municipality, such equipment cannot be changed and therefore is not considered in the renovation plan.

Near to the reception in floor 0 there are 2 vending machines.

The building has 2 lifts (they can be observed in the plans for instance in the areas 78 and 79 of floor -1). The use of such lifts is low since they serve areas without public.

There are 2 small goods lifts to ensure the transportation of books between silos (they can be observed in the plans for instance in the area 74 of floor -1).

6.3. Energy Consumption and Energy Generation

6.3.1. Electricity Consumption

The building receives electricity in Medium Voltage (MV) and has a transformer (using oil refrigeration) with 630 kVA to ensure the conversion to Low Voltage. The contracted power must be at least 50% of the installed power, corrected by the power factor. Then, the contracted power is 292.95 kW. The characteristics of the contract are presented in Table 57.

TABLE 57: CHARACTERISTICS OF THE ELECTRICITY CONTRACT

Voltage Level	Medium Voltage (15 kV)
Contracted Power	292.95 kW
Tariff Option	Energy + Grid + MV
Cycle	Weekly + public holidays

To a weekly cycle in MV there are 4 different tariff periods, which are presented in Table 58.

TABLE 58: SCHEDULE OF THE TARIFF PERIODS

Period	Winter	Summer
Weekdays		
On-Peak	09h30 – 12h00 18h30 – 21h00	9h15 – 12h15
Mid-Peak	07h00 – 09h30 12h00 – 18h30 21h00 – 24h00	07h00 – 9h15 12h15 – 24h00
Normal Off-Peak	00h00 – 02h00 06h00 – 07h00	00h00 – 02h00 06h00 – 07h00
Super Off-Peak	02h00 – 06h00	02h00 – 06h00
Saturdays		
Mid-Peak	09h30 – 13h00 18h30 – 22h00	09h00 – 14h00 20h00 – 22h00
Normal Off-Peak	00h00 – 02h00 06h00 – 09h30 13h00 – 18h30 22h00 – 24h00	00h00 – 02h00 06h00 – 09h00 14h00 – 20h00 22h00 – 24h00
Super Off-Peak	02h00 – 06h00	02h00 – 06h00
Sundays and Public Holidays		
Normal Off-Peak	00h00 – 02h00 06h00 – 24h00	00h00 – 02h00 06h00 – 24h00
Super Off-Peak	02h00 – 06h00	02h00 – 06h00

In 2013 the building had an electricity consumption of about 521 MWh and an associated cost of about 84 k€. Table 59 presents the evolution of the consumption and costs between 2011 and 2013. As can be seen the consumption have been decreasing during the last 2 years.

TABLE 59: EVOLUTION OF THE CONSUMPTION AND COSTS DURING THE LAST 3 YEARS

Year	Parameter	1st Q	2nd Q	3rd Q	4th Q	Total	Avg Day
2011	Consump. (kWh)	202,686.4	146,740.5	123,393.9	148,830.8	621,651.6	1,703.2
	Cost € (w/ VAT)	22,332.7	16,968.6	14,366.6	19,382.7	73,050.5	200.1
2012	Consump. (kWh)	164,727.2	137,597.7	110,306.0	143,074.3	555,705.1	1,522.5
	Cost € (w/ VAT)	27,182.0	20,500.0	16,859.9	21,129.5	85,671.4	234.7
	Δ Cons. (kWh)	-37,959.3	-9,142.8	-13,087.9	-5,756.6	-65,946.5	-180.7
	Δ Consump. (%)	-18 .3%	-6.23%	-10.61%	-3.87%	-10.61%	-10.61%
2013	Consump. (kWh)	160,445.3	113,702.5	112,098.9	134,337.4	520,584.1	1,426.3
	Cost € (w/ VAT)	25,652.8	19,003.5	18,432.0	21,110.5	84,198.7	230.7
	Δ Cons. (kWh)	-4,281.9	-23,895.2	1,793.0	-8,736.9	-35,121.0	-96.2
	Δ Consump. (%)	-2.60%	-17.37%	1.63%	-6.11%	-6.32%	-6.32%

This is not due to any major replacement of equipment or reduction of use. The main reasons for such decrease on the energy consumption are: nowadays the refectory just serves lunches and works as cafeteria (until 2011 the refectory also served dinners); there are several lamps burned out and some incandescent lamps were replaced by CFLs; 4 of the 9 systems of temperature and humidity control are not working.

Figure 65 and Figure 66 present the evolution of the monthly electricity consumption and costs between 2008 and 2013. As can be seen the different years present a similar variation of consumption between months, with a higher consumption during winter.

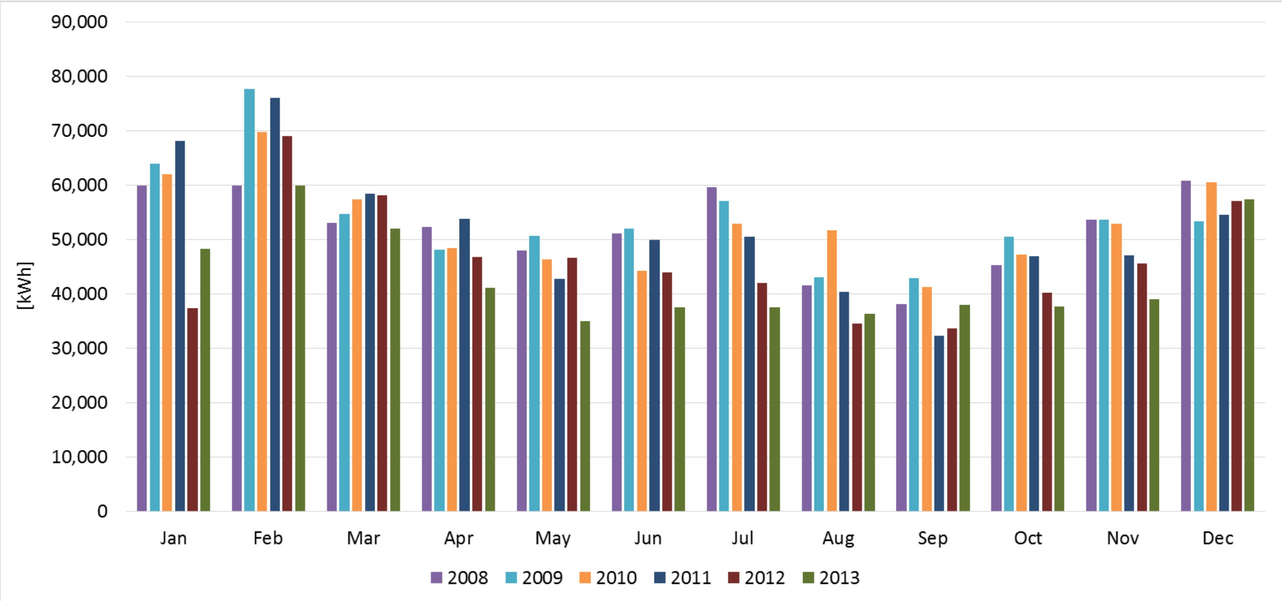


Figure 65: Monthly consumption between 2008 and 2013

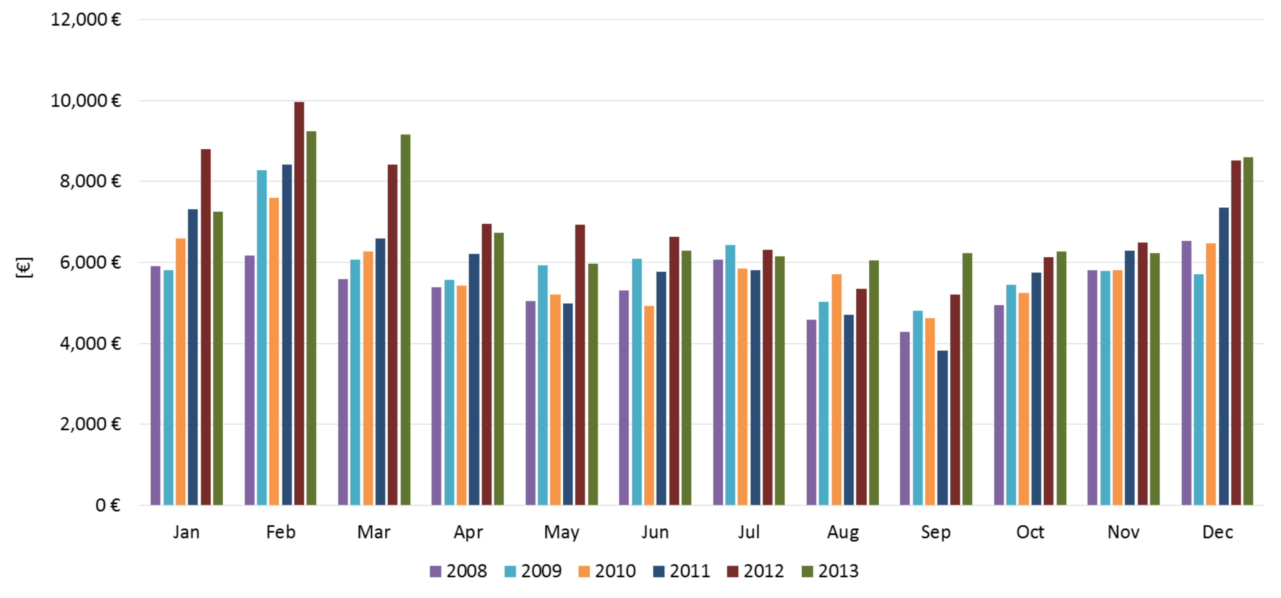


FIGURE 66: MONTHLY COSTS BETWEEN 2008 AND 2013

As can be seen in Figure 67 and Figure 68, the distribution between tariff periods does not present large variations between the different months, being in average: 21.2% in on-peak; 63.1% in mid-peak; 11.3% in normal off-peak and 4.3% in super off-peak.

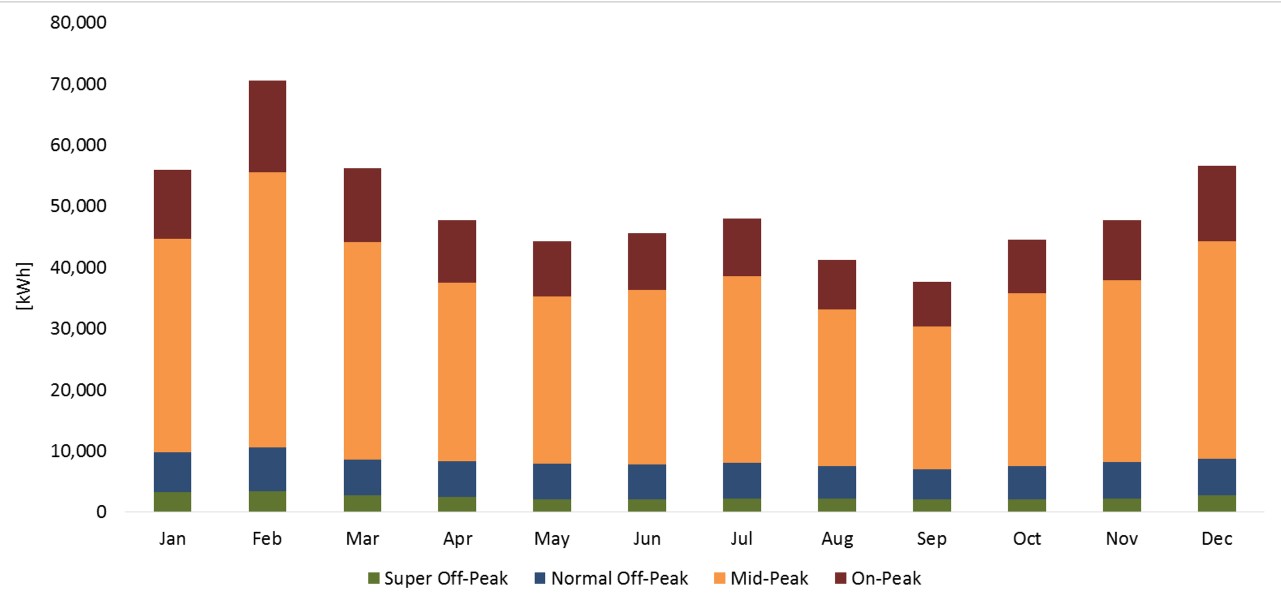


FIGURE 67: MONTHLY DISAGGREGATION BETWEEN TARIFF PERIODS IN THE AVERAGE 2008-2013 (KWH)

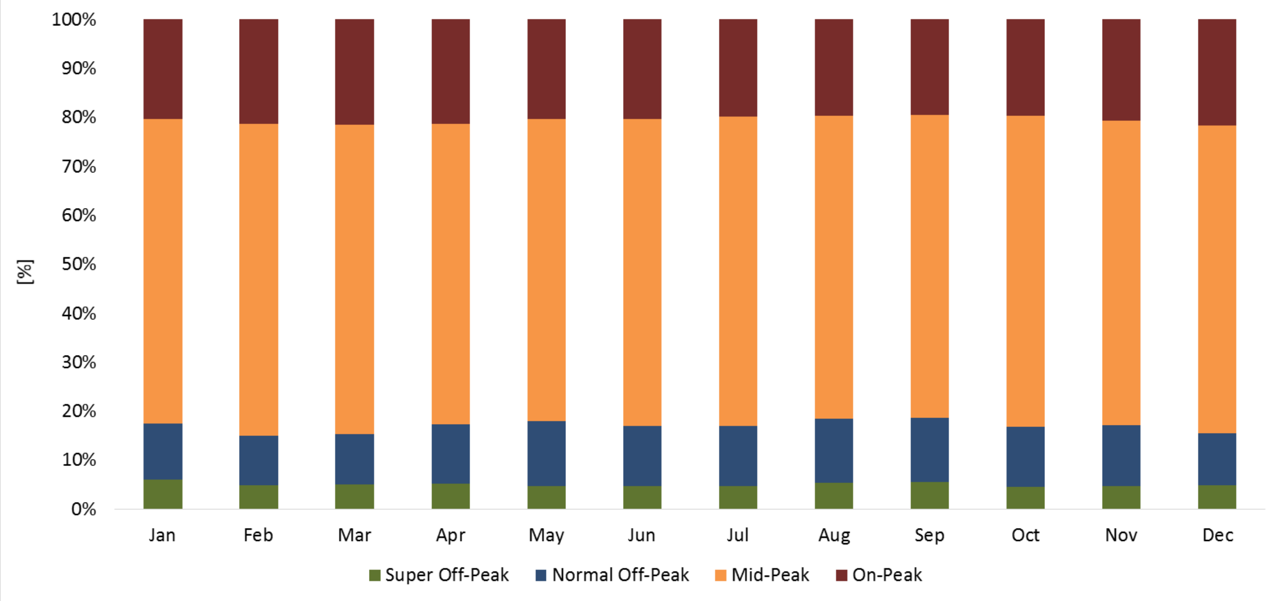


Figure 68: Monthly disaggregation between tariff periods in the average 2008-2013 (%)

Figure 69 presents the consumption profile during one week of summer and Figure 70 presents the consumption profile during one week of winter.

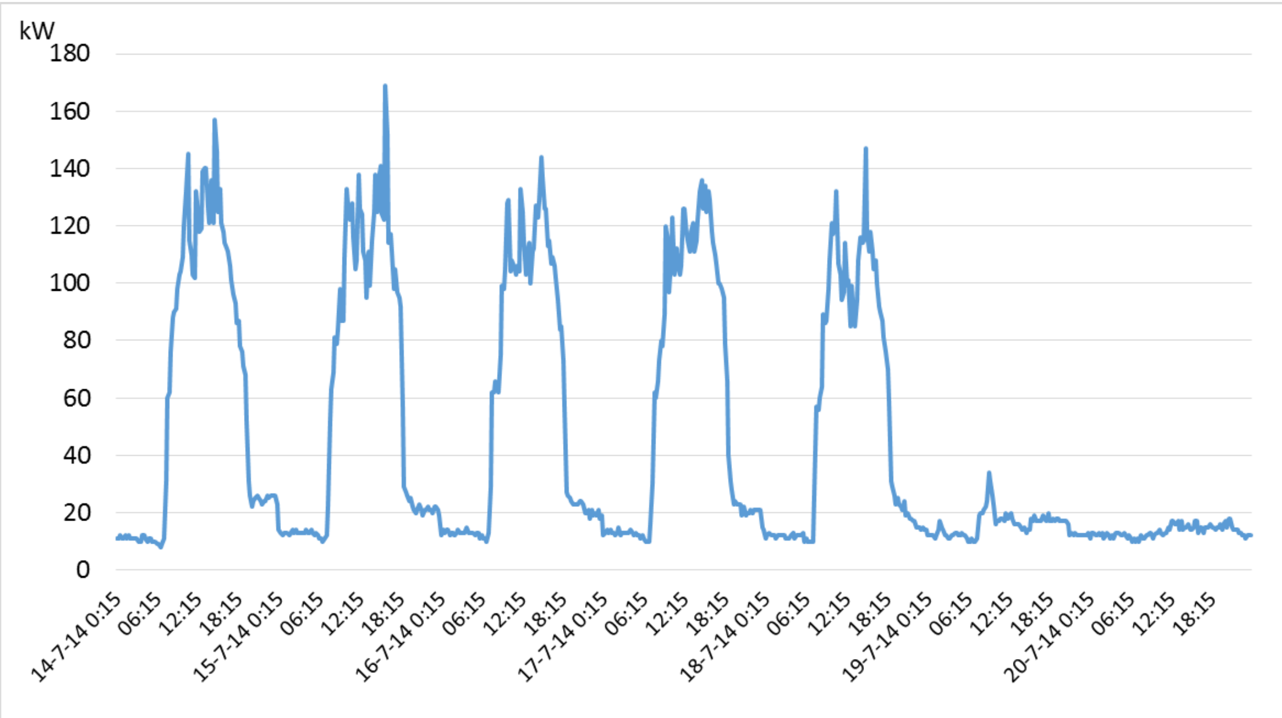


FIGURE 69: CONSUMPTION PROFILE IN THE MAIN ELECTRICAL BOARD (SUMMER)

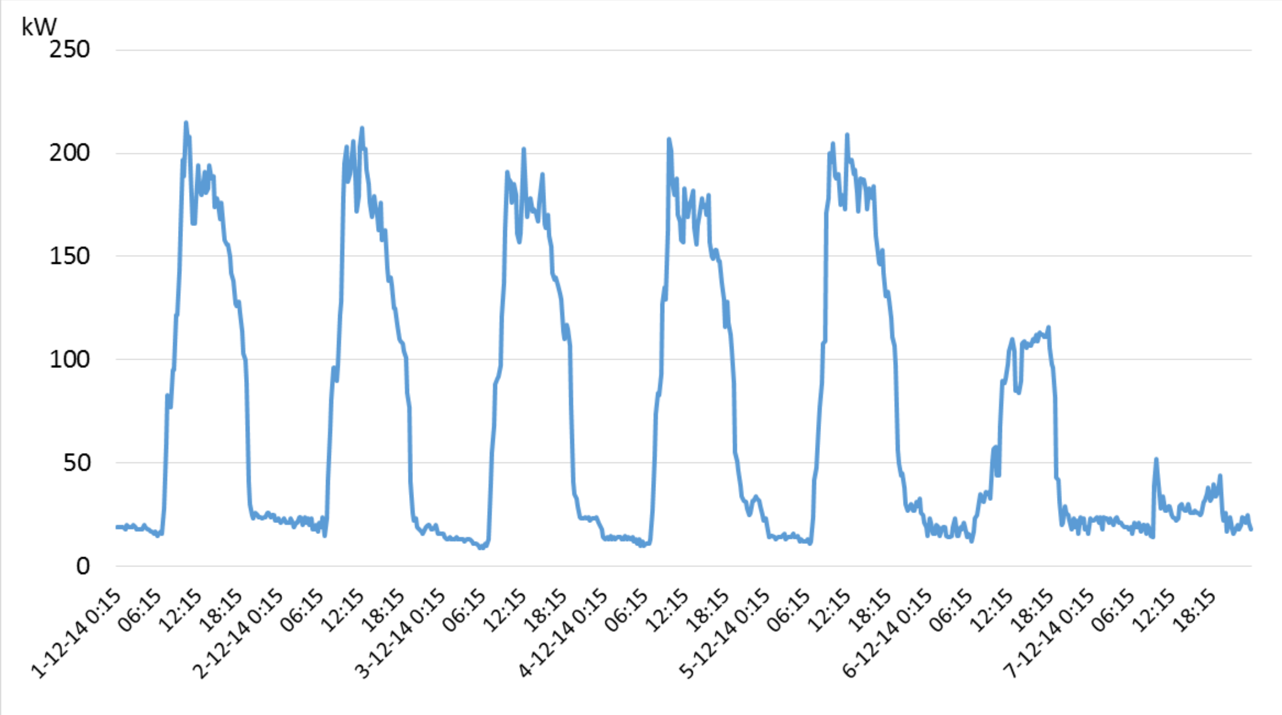


FIGURE 70: CONSUMPTION PROFILE IN THE MAIN ELECTRICAL BOARD (WINTER)

Figure 71 and Figure 72 (excluding the refectory) presents the disaggregation of electricity consumption between uses, based on the data available from consumption monitoring and use of electrical equipment. The consumption is mainly divided between 3 major uses: lighting, HVAC and the refectory.

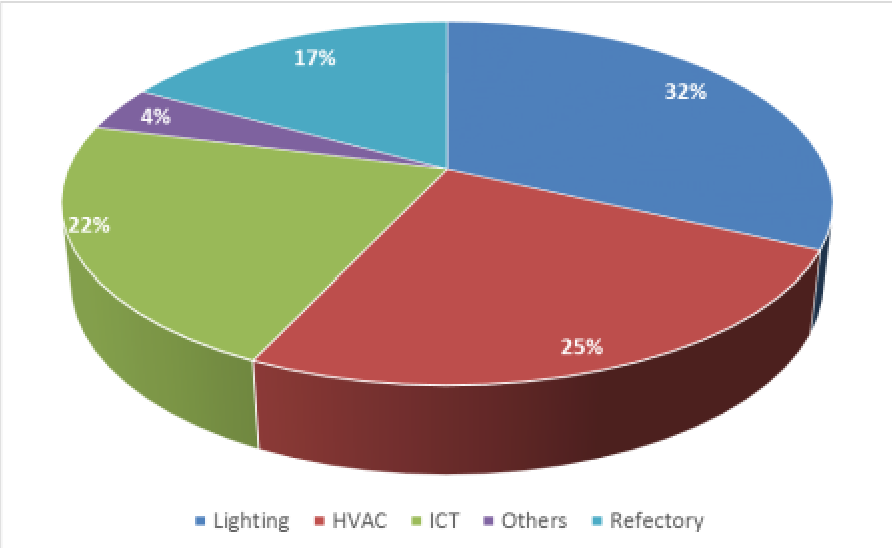


FIGURE 71: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES

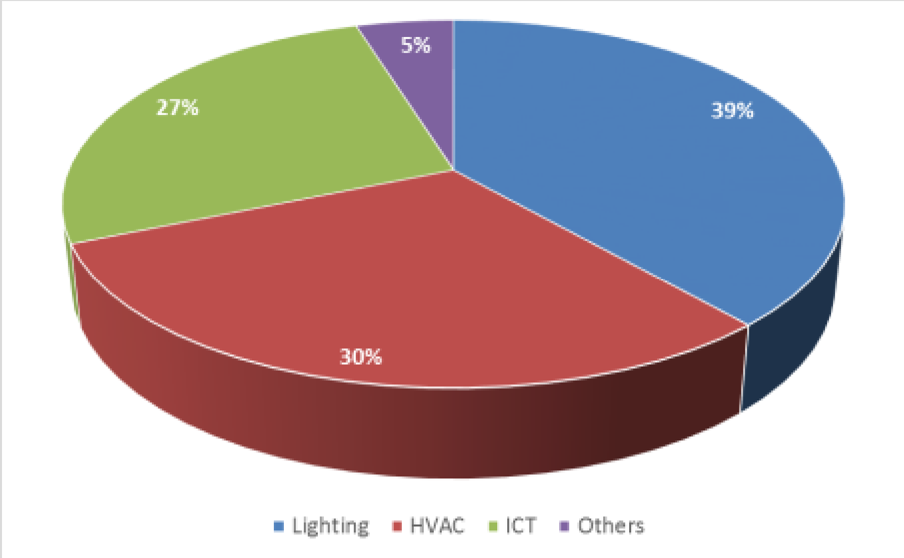


FIGURE 72: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES, EXCLUDING THE REFECTORY

6.3.2. Gas/Oil Consumption

There is only gas consumption in the University refectory. However, this area is not managed by the Municipality and the gas is paid by the University.

6.3.3. Renewable Energy Sources

The building does not have any renewable energy sources.

6.3.4. Other Generation

The building has a backup diesel generator with 80 kVA (Figure 73).

FIGURE 73: BACKUP DIESEL GENERATOR

6.3.5. Final Energy Consumption and CO_2 Emissions

During 2013 the buildings had an electricity consumption of 520,584 kWh (Table 60). However, 17% of this consumption is due to refectory of the University. Since this space is not managed by the Municipality, its equipment cannot be changed and therefore is not considered in the renovation plan. Additionally, it was detected that 4 of the 9 systems of temperature and humidity control (THC) are not working and since this is not the normal mode of operation, the electricity consumption for the baseline should be corrected to take into account the consumption of the 9 systems.

TABLE 60: ENERGY CONSUMPTION IN 2013

Consumption kWh	Including Refectory	Excluding Refectory
Electricity	520,584	432,084
Electricity (with 9 THC)	575,729	487,229
Gas	0	0

Table 61 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 - 2.5 (standard value approved for Portugal);
- natural gas to primary energy - 1.0 (standard value);
- electricity to CO_2 emissions - 139.89 g/kWh (average emissions associated with the electricity consumed in Portugal during 2013);
- natural gas to CO_2 emissions - 202 g/kWh (standard value).

TABLE 61: ENERGY PARAMETERS

	Final Energy kWh	Energy Dens. kWh/m^2	Primary Energy kWh	CO_2 Emissions kg CO_2 /kWh
Electricity	487,229	49.4	1,218,073	68,158.5
Gas	0	0	0	0
Generation	0	0	0	0
Total	487,229	49.4	1,218,073	68,158.5

7. Renovation Scheme

7.1. Aim of the Renovation Plan

The objective of the renovation plan 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. However, since there is enough available roof area without shadings and with a good solar radiation levels the aim was redefined to achieve a minimum primary energy reduction of 95%, ensuring, at least, 95% of the consumption with renewable energy sources, therefore achieving almost a Zero Energy Level.

The following global constraints were taken into account in the design of the renovation plan:

- Part of floor -2 is a refectory from the University of Coimbra. However, this refectory receives electricity from the school without any individual metering. Therefore, its consumption is included in the total consumption of the building, but such energy consumption cannot be considered as a consumption of the studied building. The consumption of the refectory was assessed (considered to be 17% of the total energy consumption) and subtracted from the total considered for the building. Therefore, the consumption level considered in the renovation plan excludes the consumption of the refectory.
- It was detected that 4 of the 9 systems of temperature and humidity control (THC) are not working and therefore the baseline was corrected to take into account the consumption of all 9 systems. Therefore, the consumption level considered in the renovation plan includes the consumption of 9 THC systems.
- The building has an intensive utilization, receiving a large number of visitors, and is the working place for a large number of Municipal employees and such activities cannot be interrupted since it is not easy to temporarily move the services to another building. Therefore, renovation options requiring major construction works, incompatible with the normal activities of the building, were avoided in the renovation plan.

7.2. Energy Demand Reduction

7.2.1. Opaque Envelope

The roof has already been renovated (replacement of the asbestos-cement slabs by a sandwich panel constituted by two thermolacquered metal sheets with 80 mm of polyurethane insulation).

Other renovation options, requiring construction works in the façades were considered. However, the renovation options requiring major construction works, incompatible with the normal activities of the building, should be avoided due to the incompatibility between use and renovation works. This is not an insurmountable barrier, but when other solutions able to achieve the same impact are available, such solutions should be preferred. Therefore, since the other solutions (efficiency of the energy systems and renewable energy resources) present enough potential to achieve the objectives and ensure higher cost-effectiveness, the renovation of the envelope was not considered in the renovation plan.

7.2.2. Openings

Due to the same reasons as in the opaque envelope (incompatibility between use and renovation works and availability of other solutions with higher cost-effectiveness) the improvement of openings was not considered in the renovation plan.

7.2.3. Other Strategies

There are no other strategies considered in the renovation for the energy demand reduction.

7.3. Energy Systems

7.3.1. Lighting System

As previously presented the actual lighting system is mainly constituted by fluorescent linear T8 lamps with electromagnetic ballast (Table 62).

TABLE 62: TYPES AND QUANTITIES OF LAMPS

Lamp Type	Quantity n	Power W
Fluorescent Linear T8 F60	9	211
Fluorescent Linear T8 F120	803	37,580
Fluorescent Linear T8 F150	312	21,091
Fluorescent Linear T5 F60	8	136
Incandescent	23	1,380
Halogen Projector	24	7,200
Halogen Spot	5	250
Compact Fluorescent	70	1,260
LED Spot	12	66
Total	**1,266**	**69,174**

Regarding the retrofit of the lighting system 2 scenarios were considered:

- Scenario 1 - Replacement of all T8 lamps with electromagnetic ballast by T5 lamps with electronic ballast and replacement of the incandescent lamps by CFLs;
- Scenario 2 - Replacement of all lamps by LEDs.

As previously explained, some rooms have a false roof in wood with small square holes, being the luminaries installed above the false roof. The installation of the lamps above the false roof causes a high loss of luminosity, which is aggravated by the difficulty of maintenance of such luminaries. These situations lead to a low visibility in some areas. Therefore, other renovation option to consider could be to move the luminaires to below the false roof. This retrofit option would ensure a better distribution of light and would facilitate the maintenance. However, such an option would not bring a major reduction of energy consumption since the power of lamps cannot be substantially decreased just due to this change. It would be possible to decrease the total power of the lighting system by decreasing the number of lamps, but such an option would require larger changes on the lighting circuits and this is not cost-effective. Just from the energy efficiency point of view this option is not cost-effective and therefore the selected option was the replacement of lamps without a change in the circuits. However, this change is a good option to increase the lighting quality and to facilitate the maintenance.

In scenario 1, 1,146 lamps and 1,124 ballasts have to be replaced. Table 63 presents the lamps and ballasts to be installed and Table 64 shows the new distribution of lamps. As can be seen the total power decreases to 51,041 W (reduction of 26%).

TABLE 63: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN SCENARIO 1

Lamp Type	Quantity n	Lamp W	Lamp+Ballast W
Fluorescent Linear T5 F150	312	49	56
Fluorescent Linear T5 F120	803	28	30
Fluorescent Linear T5 F60	9	14	17
Compact Fluorescent	23	18	-

TABLE 64: TYPES AND QUANTITIES OF LAMPS CONSIDERED IN SCENARIO 1

Lamp Type	Quantity n	Total Power W
Fluorescent Linear T8 F150	312	17,472
Fluorescent Linear T8 F120	803	24,090
Fluorescent Linear T8 F60	17	289
Compact Fluorescent	93	1,674
Halogen Projector	24	7,200
Halogen Spot	5	250
LED Spot	12	66
Total	**1,266**	**51,041**

In scenario 2, 1,254 lamps have to be replaced. Table 65 presents the lamps to be installed and Table 66 show the new distribution of lamps. As can be seen the total power decreases to 27,095 W (reduction of 61%).

TABLE 65: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN SCENARIO 2

Lamp Type	Quantity n	Lamp W
LED Linear F150	312	24.0
LED Linear F120	803	20.0
LED Linear F60	17	10.0
LED Bulb	93	9.5
LED Projector	24	100.0
LED Spot	5	5.5

TABLE 66: TYPES AND QUANTITIES OF LAMPS CONSIDERED IN SCENARIO 2

Lamp Type	Quantity n	Total Power W
LED Linear F150	312	7,488.0
LED Linear F120	803	16,060.0
LED Linear F60	17	170.0
LED Bulb	93	883.5
LED Projector	24	2,400.0
LED Spot	17	93.5
	1,266	**27,095**

Table 67 presents the yearly consumption with lighting in the 2 scenarios, as well as the percentage of achievable savings. Such energy consumptions were simulated considering the actual usage profile for each lamp type and room of the building. As can be seen, scenario 1 ensures 26% and scenario 2 ensures 61% of energy savings.

TABLE 67: YEARLY CONSUMPTION WITH LIGHTING IN THE 2 SCENARIOS

	Actual	Scenario 1	Scenario 2
Consumption (kWh)	166,930	123,530	65,773
Savings (kWh)	-	43,400	101,157
Savings (%)	-	26.0%	60.6%

7.3.2. HVAC System

As previously presented the HVAC system is constituted by two main types of technologies: multi-split systems systems of temperature and humidity control; mono-split systems with heat pumps.

The systems of temperature and humidity control are constituted by 9 units with the characteristics presented in Table 68. The systems originally had EER of 2.43 and COP of 2.97, but since the system has more than 20 years old it was considered a reduction of efficiency, decreasing the EER to 2.0 and the COP to 2.2. As previously mentioned, it was considered the use of the 9 systems (4 systems are not currently in operation).

TABLE 68: TECHNICAL DATA OF THE CIATESA ISW-120

$P_{cooling-ther}$ (kW)	$P_{cooling-elect}$ (kW)	EER	$P_{heating-ther}$ (kW)	$P_{heating-ther}$ (kW)	COP	$P_{compressor}$ (kW)	$P_{ventilator}$ (kW)
29.7	12.2	2.43	30.3	10.2	2.97	7.5	1.1

In the renovation plan the replacement of such system by new systems with higher efficiency was considered, being selected a system with EER of 5.2 and COP of 5.74 (Table 69).

TABLE 69: TECHNICAL DATA OF THE NEW THC SYSTEMS

$P_{cooling-ther}$ (kW)	EER	$P_{heating-ther}$ (kW)	COP	Quantity
28	5.2	31.5	5.74	9

The HVAC in most of the building is ensured by mono-split systems with heat pumps installed in the wall or roof with a total power of 239.27 kW. Most of the systems are old and do not present technical data to characterize its efficiency. Therefore, it was considered an average EER of 2.0 and a COP of 2.2.

The replacement of the several mono-split systems by multi-split systems was not considered, since despite the potential lower purchase cost of multi-split systems the costs of installation would be higher and mainly the impact of the installation process on the building operation would be much higher. Therefore, it was considered the replacement by other mono-split systems with higher efficiency, keeping the same total power. Table 70 presents the characteristics and distribution of mono-split systems considered in the renovation.

TABLE 70: TECHNICAL DATA OF THE NEW MONO-SPLIT SYSTEMS

P_{ind} (kW)	EER	COP	Quantity	P_{total} (kW)
2.5	9.1	5.2	5	12.5
3.5	8.9	5.1	10	35.0
5.2	6.1	3.8	16	83.2
6.8	6.1	3.8	16	108.8
	6.7	**4.1**	**47**	**239.5**

Table 71 presents the annual consumption with HVAC in the actual and retrofit scenarios. Such energy consumptions were simulated considering the actual usage profile and the change of COP/EER. As can be seen, the retrofit ensures 62% of energy savings.

TABLE 71: YEARLY CONSUMPTION WITH THE HVAC SYSTEM

		Actual	Scenario 1
Considering the operation of 5 THC			
THC	Consumption (kWh)	75,000	28,793
	Savings (kWh)	-	46,207
	Savings (%)	-	61.6%
Mono	Consumption (kWh)	68,932	26,982
	Savings (kWh)	-	41,950
	Savings (%)	-	60.9%
Total	Consumption (kWh)	143,932	55,775
	Savings (kWh)	-	88,157
	Savings (%)	-	61.2%
Considering the operation of 9 THC			
THC	Consumption (kWh)	124,078	47,635
	Savings (kWh)	-	76,443
	Savings (%)	-	61.6%
Mono	Consumption (kWh)	68,932	26,982
	Savings (kWh)	-	41,950
	Savings (%)	-	60.9%
Total	Consumption (kWh)	193,010	74,617
	Savings (kWh)	-	118,393
	Savings (%)	-	61.3%

As previously explained, all the windows used in the building are of single glazing with aluminium frames. The replacement of windows by double glazing windows was not considered in this plan since the option to replace the HVAC system present higher cost-effectiveness and is more easily assessed and monitored. However, such replacement should be considered in future renovations of the building.

7.3.3. ICT and Others

ICT appliances (mainly PCs, monitors and printers) represent an important share of the consumption. The replacement of such appliances by new devices is not cost-effective just from the energy savings point of view and therefore this is not considered in the renovation plan. However, in the regular replacement of ICT appliances it is recommended to install just ICT appliances with lower energy consumption.

From the energy savings point of view, the most cost-effective solution is the installation of devices to reduce the standby consumption of ICT appliances, the so-called standby killers. However, the potential savings achieved with such devices do not depend on the technology, but on the users' behaviour and therefore a reliable assessment of savings is not possible. Therefore, such measures are not included in the renovation plan, due to the difficulty of assessment, but its future implementation is recommended.

The building also has 2 lifts and 2 small goods lifts. However, the use of such lifts is low since they serve areas without public and therefore the replacement of such lifts by systems with higher efficiency is not cost-effective.

7.4. Renewable Energy Sources

7.4.1. PV Generation

Figure 74 shows the different roof areas of the building.

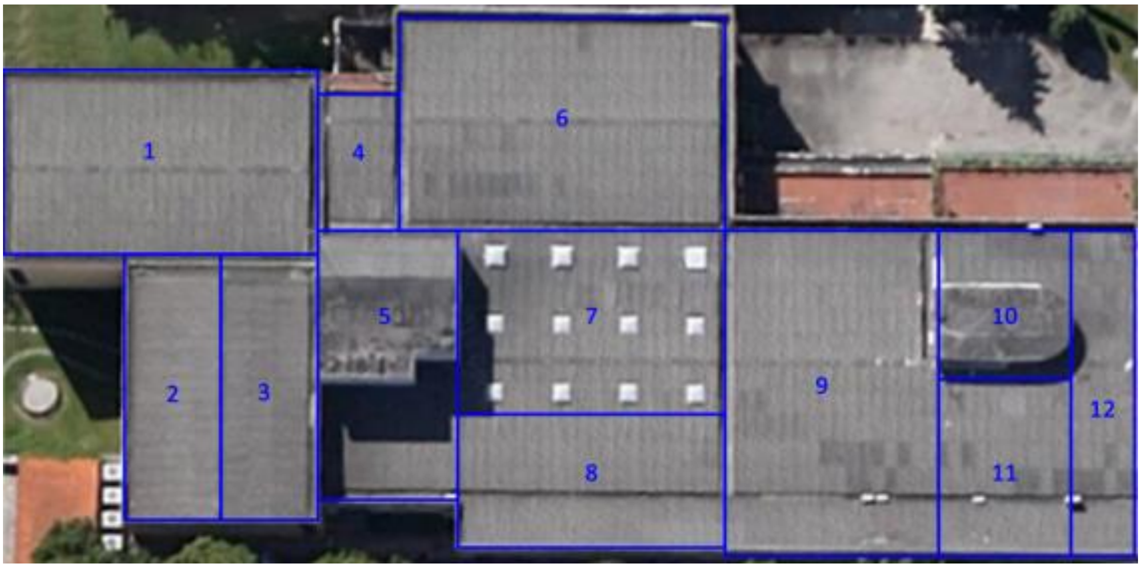


FIGURE 74: ROOF AREAS

It was not considered the installation of PV panels in the areas 3, 4, 5, 7 and 10 due to the following reasons:

- Area 3 – due to a negative slope of the roof, to install PV panels a larger structure with high visual impact would be required;
- Area 4 – reduced potential due to the shading caused by the additional floor in area 5;
- Area 5 – reduced potential due to the shading caused by area 3 and part of this area is constituted by an additional floor;
- Area 7 – the installation of PV panels would cause shading on the skylights;
- Area 10 – reduced potential due to the shading caused by the additional floor.

In the remaining areas, it was considered the installation of PV panels oriented to south, but keeping the orientation of the building (azimuth of 20º) in order to minimize the visual impact of the PV panels. It was considered the use of PV modules SINERGIAE PiFoton Premium 235 (Table 72). The PV panels would be installed in structures with a tilt of 30º, as shown in Figure 75, being side with 1,639 mm aligned with the distance A of the structure.

TABLE 72: CHARACTERISTICS OF THE PV MODULES

Electrical Characteristics	
Minimum guaranteed power	235 W
Voltage at maximum power	29.58 V
Current at maximum power	7.95 A
Short-circuit current	8.57 A
Open-circuit voltage	38.10 V
Mechanical Characteristics	
Dimensions	1,639 x 989 x 35 mm
Weight	20 kg

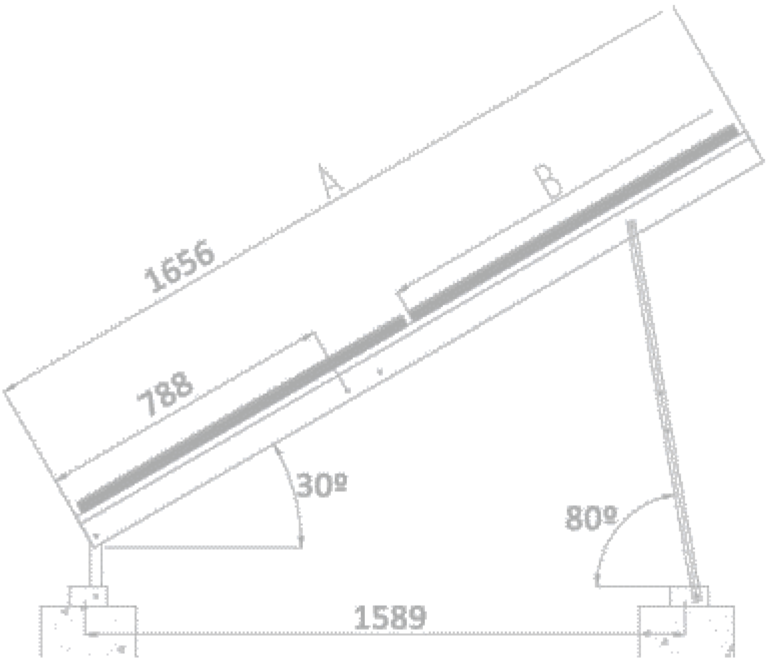


FIGURE 75: STRUCTURES OF THE PV PANELS

Considering the available area, the needed spacing between the panels and the restriction to have a total number of panels that can be associated in series and parallel, the number of PV panels that can be installed in each area are the following:

- Area 1 - 154
- Area 2 - 34
- Area 6 - 224
- Area 8 - 108
- Area 9 - 168
- Area 11 - 60
- Area 12 - 22

Therefore, it was considered the installation of 770 PV panels, ensuring an installed power of 181 kWp. This scenario was simulated with PVSYST using the following parameters for the site and simulation (Table 73 and Table 74, respectively).

TABLE 73: SITE PARAMETERS

Geographical Site	Coimbra
Country	Portugal
Latitude	40.1°N
Longitude	8.2°W
Time	Defined as Legal Time
Time zone	UT+1
Altitude	141 m
Albedo	0.20
Meteo data	Coimbra, Synthetic Hourly data

TABLE 74: SIMULATION PARAMETERS

Collector Plane Orientation	Tilt 30° Azimuth 20°
Horizon	Free Horizon
Near Shadings	No Shadings

The 770 panels were considered to be connected with series of 22 modules and 33 strings in parallel. Table 75 presents the PV array characteristics, Table 76 presents the inverter characteristics and Table 77 presents the PV array loss factors.

TABLE 75: PV ARRAY CHARACTERISTICS

PV module	Si-poly
Model	SINPRIME PREMIUM 235
Manufacturer	SINERGIAE
Number of PV modules	In series 22 modules In parallel 35 strings
Total number of PV modules	770
Unit Nom. Power	235 Wp
Array global power	Nominal (STC) 181 kWp At operating cond. 163 kWp (50°C)
Array operating characteristics (50°C)	U mpp 593 V I mpp 274 A
Total area	Module area 1248 m² Cell area 462 m²

TABLE 76: INVERTER CHARACTERISTICS

Model	Powador 36 TL3 M
Manufacturer	KACO new energy
Characteristics	Operating Voltage 200-800 V Unit Nom. Power 30 kW AC
Inverter pack	Number of Inverter 5 units Total Power 150 kW AC

TABLE 77: PV ARRAY LOSS FACTORS

Thermal Loss factor	Uc (const) 20.0 W/m²K Uv (wind) 0.0 W/m²K / m/s
Nominal Oper. Coll. Temp.	NOCT 56 °C (G=800 W/m², Tamb=20°C, Wind=1 m/s.)
Wiring Ohmic Loss	Global array res. 36 mOhm Loss Fraction 1.5 % at STC
Module Quality Loss	Loss Fraction 1.5 %
Module Mismatch Losses	Loss Fraction 2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM = 1 - bo (1/cos i - 1) bo Parameter 0.05

With these parameters, the following performance ratio (Figure 76) and loss diagram (Figure 77) over the whole year were obtained.

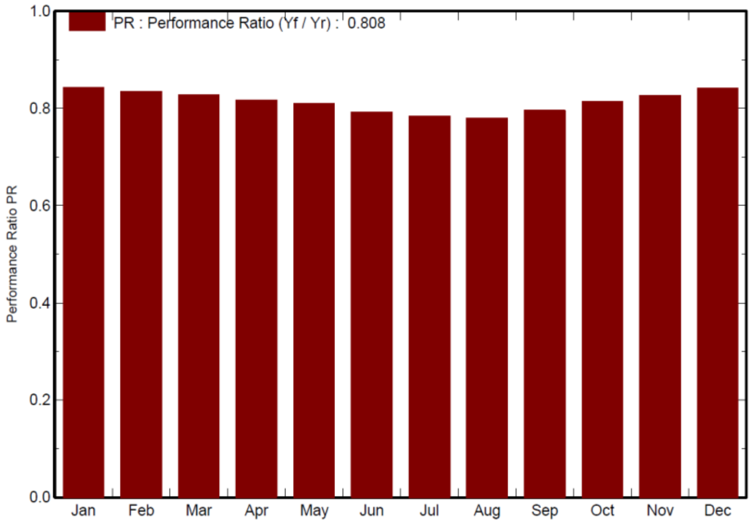


FIGURE 76: PERFORMANCE RATIO PR

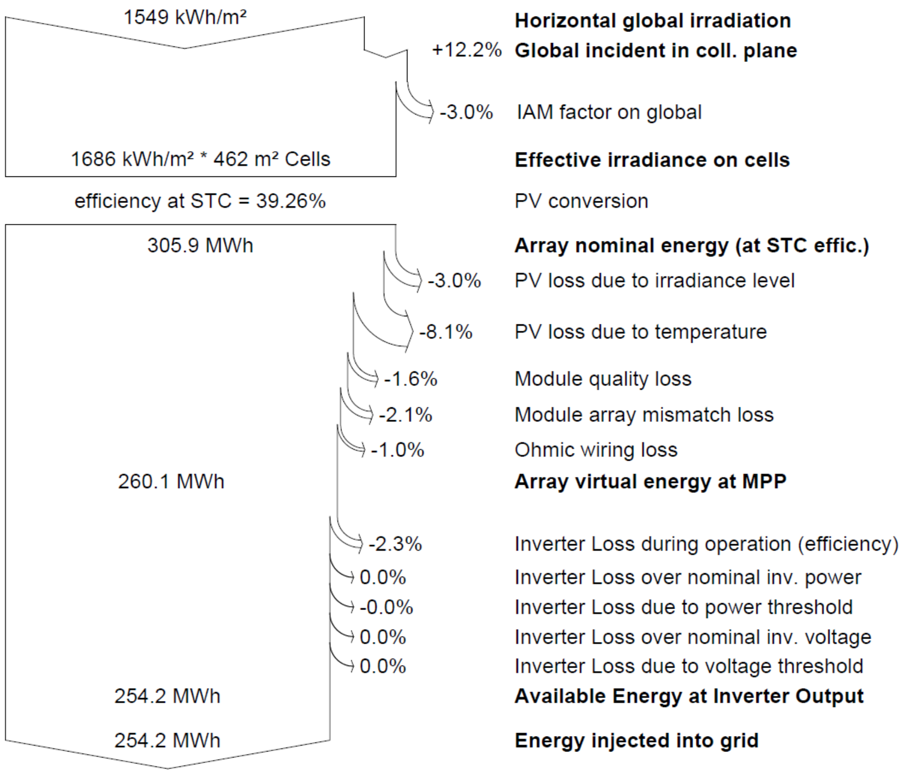


FIGURE 77: LOSS DIAGRAM OVER THE WHOLE YEAR

As can be seen in Table 78, this scenario ensures a generation of 254.2 MWh/year, with a specific production of 1,405 kWh/kWp/year and a performance ratio of 80.8 %. Table 79 presents the variation during the whole year of the irradiation, temperature, energy and efficiency.

TABLE 78: MAIN SIMULATION RESULTS IN SCENARIO 1

Produced Energy	254.2 MWh/year
Specific prod.	1,405 kWh/kWp/year
Performance Ratio PR	80.8 %

TABLE 79: BALANCES AND SIMULATION RESULTS

[6]	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
Jan	61.0	10.00	93.5	90.5	14.59	14.26	12.50	12.22
Feb	73.0	11.00	98.5	95.6	15.21	14.87	12.38	12.10
Mar	129.0	12.50	154.9	150.5	23.71	23.18	12.26	11.99
Apr	140.0	14.00	149.0	144.6	22.53	22.02	12.11	11.84
May	179.0	16.40	175.3	170.1	26.28	25.69	12.01	11.74
Jun	195.0	19.60	182.0	176.5	26.69	26.07	11.75	11.48
Jul	209.0	21.80	198.8	192.8	28.88	28.22	11.64	11.37
Aug	195.0	21.80	200.5	194.8	28.97	28.30	11.58	11.31
Sep	147.0	20.80	169.7	164.9	24.99	24.44	11.80	11.54
Oct	104.0	17.40	136.0	132.0	20.49	20.04	12.07	11.80
Nov	63.0	13.00	92.7	89.8	14.18	13.85	12.25	11.97
Dec	54.0	10.40	87.2	84.3	13.57	13.26	12.47	12.19
Year	**1,549.0**	**15.75**	**1,738.0**	**1,686.3**	**260.09**	**254.21**	**11.99**	**11.72**

The variation during the year of the normalized generation (per installed kWp) is presented in Figure 78 and the variation of the energy injected into grid is presented in Figure 79.

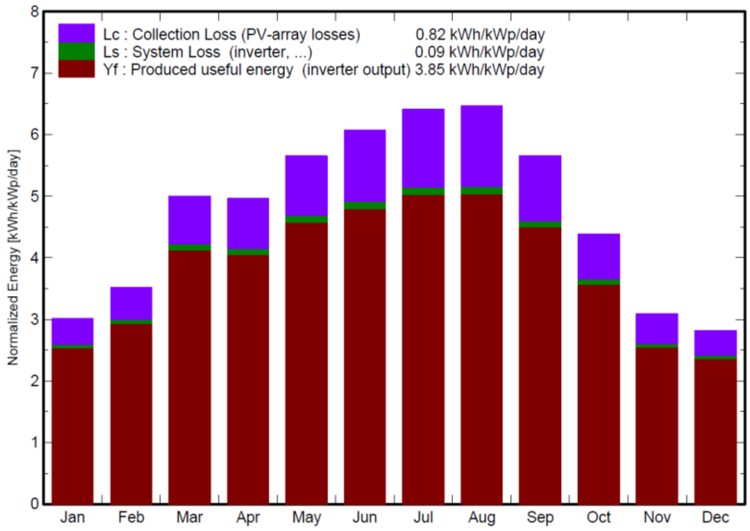


FIGURE 78: NORMALIZED GENERATION (PER INSTALLED KWP)

[6] GlobHor - Horizontal global irradiation; T Amb - Ambient Temperature; GlobInc - Global incident in coll. Plane; GlobEff - Effective Global, corr. for IAM and shadings; EArray - Effective energy at the output of the array; E_Grid - Energy injected into grid; EffArrR - Effic. Eout array / rough area; EffSysR - Effic. Eout system / rough area

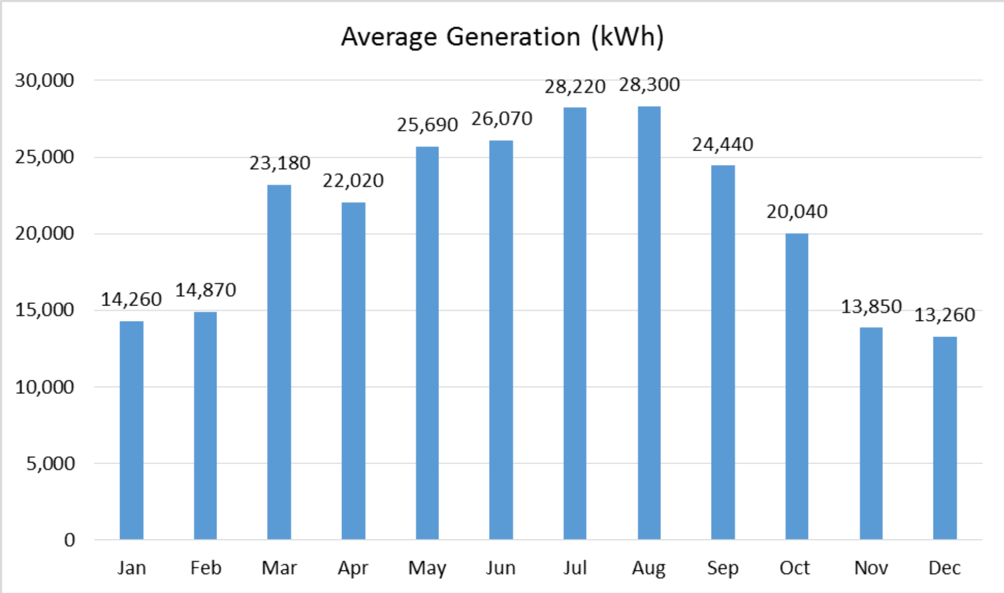


FIGURE 79: ENERGY INJECTED INTO GRID

Table 80 presents the yearly generation, as well as the percentage of consumption that can be ensured. As can be seen, excluding the consumption of the refectory, it ensures about 59% of the actual energy needs and 53% of the consumption if the operation of the 9 THC is considered. As presented in detail in section 8.2, it was considered that 10% of the yearly generation has to be injected into the electrical grid.

TABLE 80: YEARLY GENERATION

	Including Refectory	Excluding Refectory
Considering the operation of the 5 THC		
Consumption (kWh)	520,584	432,084
Generation (kWh)	254,200	254,200
Generation (% of Cons.)	48.8%	58.8%
Considering the operation of the 9 THC		
Consumption (kWh)	575,729	487,229
Generation (kWh)	254,200	254,200
Generation (% of Cons.)	44.2%	52.2%

7.4.2. Solar Thermal Collectors

The building does not have a regular need of hot water and therefore the installation of solar thermal collectors was not considered in the renovation plan.

7.4.3. CHP

The building does not have a constant need of heating and therefore the installation of CHP technologies was not considered in the renovation plan.

7.5. Total Impact of the Renovation Scheme

7.5.1. Energy Performance

In the assessment of the total impact the following individual scenarios were considered:

- PV – 770 PV panels;
- Light1 – replacement of all T8 lamps with electromagnetic ballast by T5 lamps with electronic ballast and replacement of the incandescent lamps by CFLs;
- Light2 - Replacement of all lamps by LEDs;
- HVAC – Replacement of the THC and mono-split system by systems with higher COP/EER.

Additionally, it was considered the aggregation of scenarios.

Table 81 (considering 5 THC) and Table 82 (considering 9 THC) present the achievable savings, as well as the net energy consumption (difference between the energy consumption and generation) in each scenario. The negative values (green) represent situations where the energy generation is higher than the energy consumption (Zero Energy Building).

TABLE 81: SAVINGS AND NET ENERGY CONSUMPTION IN SEVERAL SCENARIOS (CONSIDERING 5 THC)

Scenario	Savings	Net-consumption			
		Inc. Refectory		Exc. Refectory	
Baseline	0 kWh	520,584 kWh	100%	432,084 kWh	100%
PV	254,200	266,384	51.2%	177,884	41.2%
Light1	43,400	477,184	91.7%	388,684	90.0%
Light2	101,157	419,427	80.6%	330,927	76.6%
HVAC	88,157	432,427	83.1%	343,927	79.6%
PV+Light1	297,600	222,984	42.8%	134,484	31.1%
PV+Light2	355,357	165,227	31.7%	76,727	17.8%
PV+HVAC1	372,593	147,991	28.4%	59,491	13.8%
PV+Light1+HVAC	415,993	104,591	20.1%	16,091	3.7%
PV+Light2+HVAC	473,750	46,834	9.0%	**-41,666**	**-9.6%**

TABLE 82: SAVINGS AND NET ENERGY CONSUMPTION IN SEVERAL SCENARIOS (CONSIDERING 9 THC)

Scenario	Savings	Net-consumption			
		Inc. Refectory		Exc. Refectory	
Baseline	0 kWh	575,729 kWh	100%	487,229 kWh	100%
PV	254,200	321,529	55.8%	233,029	47.8%
Light1	43,400	532,329	92.5%	443,829	91.1%
Light2	101,157	474,572	82.4%	386,072	79.2%
HVAC	118,393	457,336	79.4%	368,836	75.7%
PV+Light1	297,600	278,129	48.3%	189,629	38.9%
PV+Light2	355,357	220,372	38.3%	131,872	27.1%
PV+HVAC1	372,593	203,136	35.3%	114,636	23.5%
PV+Light1+HVAC	415,993	159,736	27.7%	71,236	14.6%
PV+Light2+HVAC	473,750	101,979	17.7%	13,479	2.8%

As can be seen, considering the use of 5 THC systems one scenario ensures a negative net energy consumption (scenario PV+Light2+HVAC). However, only the scenarios with the use of 9 THC systems should be considered, since the actual use of just 5 THC systems is not the normal operation of the building.

Considering the use of 9 THC systems and including the consumption of the refectory the best scenario reduces the net energy consumption for 17.7%. However, as previously explained the scenario to be considered should not include the refectory since such area is not managed by the Municipality. In this situation one scenario (scenario PV+Light1+HVAC) ensures a low net energy consumption (14.6%) and other scenario (scenario PV+Light+HVAC) ensures almost a zero net energy consumption (2.8%), being the selected scenario.

The selected scenario is constituted by:

- Installation of 770 PV panels;
- Replacement of all lamps by LEDs;
- Replacement of the THC and mono-split systems by systems with higher COP/EER.

7.5.2. Environmental Performance

As can be seen in Table 83 with the renovation 95.1% of the consumed energy is ensured by renewable energy sources, therefore achieving the aim of 95% renewable energy sources.

TABLE 83: RENEWABLE GENERATION SHARE

	Energy Consumption kWh	Energy Generation kWh	Energy Generation %
Renovation	267,279	254,200	95.1%

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

- electricity to primary energy - 2.5 (standard value approved for Portugal);
- electricity to CO_2 emissions - 139.89 g/kWh (average emissions associated with the electricity consumed in Portugal during 2013);

As can be seen in Table 84 the renovation plan can ensure 97.2% savings in final energy, primary energy and CO_2 emissions, therefore achieving the aim of 95% of primary energy reduction.

TABLE 84: FINAL ENERGY, PRIMARY ENERGY AND CO_2 EMISSIONS SAVINGS

	Final Energy kWh	Energy Dens. kWh/m^2	Primary Energy kWh	CO_2 Emissions kg CO_2 /kWh
Electricity base.	487,229	49.4	1,218,073	68,158.5
Gas base.	0	0	0	0
Total base.	487,229	49.4	1,218,073	68,158.5
Electricity renov.	13,479	1.4	33,697.5	1,885.6
Gas renov.	0	0	0	0
Total renov.	13,479	1.4	33,697.5	1,885.6
Savings	473,750	48.0	1,184,375	66,272.9
Savings (%)	97.2%	97.2%	97.2%	97.2%

8. Economic Evaluation of the Proposed Renovation Scheme

8.1. Assumptions and Cost Figures

The costs of the selected renovation options were determined by consulting catalogues and installers and considering a typical reduction of costs due to the quantity.

Table 85 presents the considered costs for the following renovation options:

- Installation of 181 kWp of PV panels (770 panels);
- Installation of 1,254 LED lamps;
- Installation of high efficiency multi and mono-split HVAC systems with a total power of 494.5 kW.

TABLE 85: COSTS OF THE SELECTED RENOVATION OPTIONS

Renovation Option	Equipment €	Installation €	Total €
PV	188,122	31,343	219,455
Lighting	17,494	3,565	21,059
HVAC	144,989	11,153	156,142
Total	**350,605**	**46,061**	**396,656**

Table 86 presents the actual tariffs of the consumed electricity in the building, disaggregated by period.

TABLE 86: ELECTRICITY TARIFFS

Period	Energy €/kWh	Grid €/kWh	Peak-Power €/kWh	Taxes €/kWh	Total €/kWh
On-Peak	0.0688	0.0338	0.0957	0.0458	0.2452
Mid-Peak	0.0651	0.0290	-	0.0219	0.1170
Normal Off-Peak	0.0486	0.016	-	0.0151	0.0807
Super Off-Peak	0.0479	0.0153	-	0.0148	0.0790

Considering the actual distribution of the consumption between periods, the average costs was obtained using 2 scenarios (Table 87): considering just the daylight hours (to be used in the evaluation of PV generation) and considering all the periods.

TABLE 87: AVERAGE COST OF THE CONSUMED ELECTRICITYY

<table>
<tr><th>Period</th><th>Cost €/kWh</th><th>Consumption %</th><th>Day €/kWh</th><th>Total €/kWh</th></tr>
<tr><td>On-Peak</td><td>0.2452</td><td>21,2%</td><td rowspan="2">0.1492</td><td rowspan="4">0.1382</td></tr>
<tr><td>Mid-Peak</td><td>0.1170</td><td>63,1%</td></tr>
<tr><td>Normal Off-Peak</td><td>0.0807</td><td>4,3%</td><td></td></tr>
<tr><td>Super Off-Peak</td><td>0.0790</td><td>11,3%</td><td></td></tr>
</table>

8.2. RESULTS

In the evaluation of the PV generation it was considered the self-consumption of 90% of the energy, since in a working day during the period of classes, the additional consumption of the refectory ensures that all the generation can be consumed locally. The exceptions are the weekends and periods without classes, since the consumption is lower and therefore part of the energy should be injected into grid. In the economic evaluation, the self-consumption was considered to avoid the average cost of energy during the daylight hours (0.1492 €/kWh), the energy injected into the grid, with the new Portuguese regulation for self-consumption, is paid with 90% of the average cost of the electricity in the Electricity Market during the correspondent month (it was considered as 0.05 €/kWh). As can be seen in Table 88, with such conditions the renovation options ensures savings of 35,405 €/year and has a simple payback period of 6.2 years.

TABLE 88: ECONOMIC PARAMETERS OF THE RENOVATION – PV GENERATION

Energy Generation	254,200 kWh
Energy - Self-Consumption	90%
Energy - Injected Into Grid	10%
Price – Self-Consumption	0.1492 €/kWh
Price - Injected Into Grid	0.05 €/kWh
Costs	219,455 €
Savings	35,405 €/year
Simple Payback	6.2 years
Lifetime	30 years
CO_2 Savings	35.56 tons/year

In the evaluation of the lighting savings it was considered the average cost of the electricity. The lifetime was assessed considering the average hours of use for the lamps and its maximum total hours of operation. As can be seen in Table 89, with such conditions the renovation options ensures savings of 13,978 €/year and has a simple payback period of 1.5 years.

TABLE 89: ECONOMIC PARAMETERS OF THE RENOVATION – LIGHTING

Energy Savings	101,157 kWh
Price - Saved Energy	0,1382 €/kWh
Costs	21,059 €
Savings	13,978 €/year
Simple Payback	1.5 years
Lifetime	10 years
CO_2 Savings	14.15 tons/year

In the evaluation of the HVAC savings it was considered the average cost of the electricity. As can be seen in Table 90, with such conditions the renovation options ensures savings of 16,359 €/year and has a simple payback period of 9.5 years.

TABLE 90: ECONOMIC PARAMETERS OF THE RENOVATION – HVAC

Energy Savings	118,393 kWh
Price - Saved Energy	0,1382 €/kWh
Costs	156,142 €
Savings	16,359 €/year
Simple Payback	9.5 years
Lifetime	20 years
CO_2 Savings	16.56 tons/year

Table 91 presents the aggregation of the renovation option. As can be seen, the total of the renovation plan ensures savings of 65,742 €/year and has a simple payback period of 6.03 years.

TABLE 91: ECONOMIC PARAMETERS OF THE RENOVATION – TOTAL

Energy Savings	473,750 kWh
Costs	396,655 €
Savings	65,742 €/year
Simple Payback	6.03 years
CO_2 Savings	66.27 tons/year

C. Town Hall

9. Building General Description

9.1. Location

The Coimbra Town Hall was built after the demolition of part of the old Monastery of Santa Cruz. The demolition works and construction was carried out mainly between 1876 and 1879, but some construction works were developed gradually until the beginning of the 20th century. Figure 80 presents the building in 1930 and Figure 81 presents it in 2014.

FIGURE 80: COIMBRA TOWN HALL IN 1930

FIGURE 81: COIMBRA TOWN HALL IN 2014

The building is located in downtown Coimbra. Table 92 presents the main location data of the building. Figure 82 and Figure 83 present the location in the city map and aerial view.

TABLE 92: LOCATION DATA OF THE BUILDING

Address	Câmara Municipal de Coimbra, Praça 8 de Maio, 3000-300 Coimbra, Portugal
Coordinates	40.211223, -8.428955
Google Maps	www.google.pt/maps/@40.2111069,-8.4285435,109m/data=!3m1!1e3

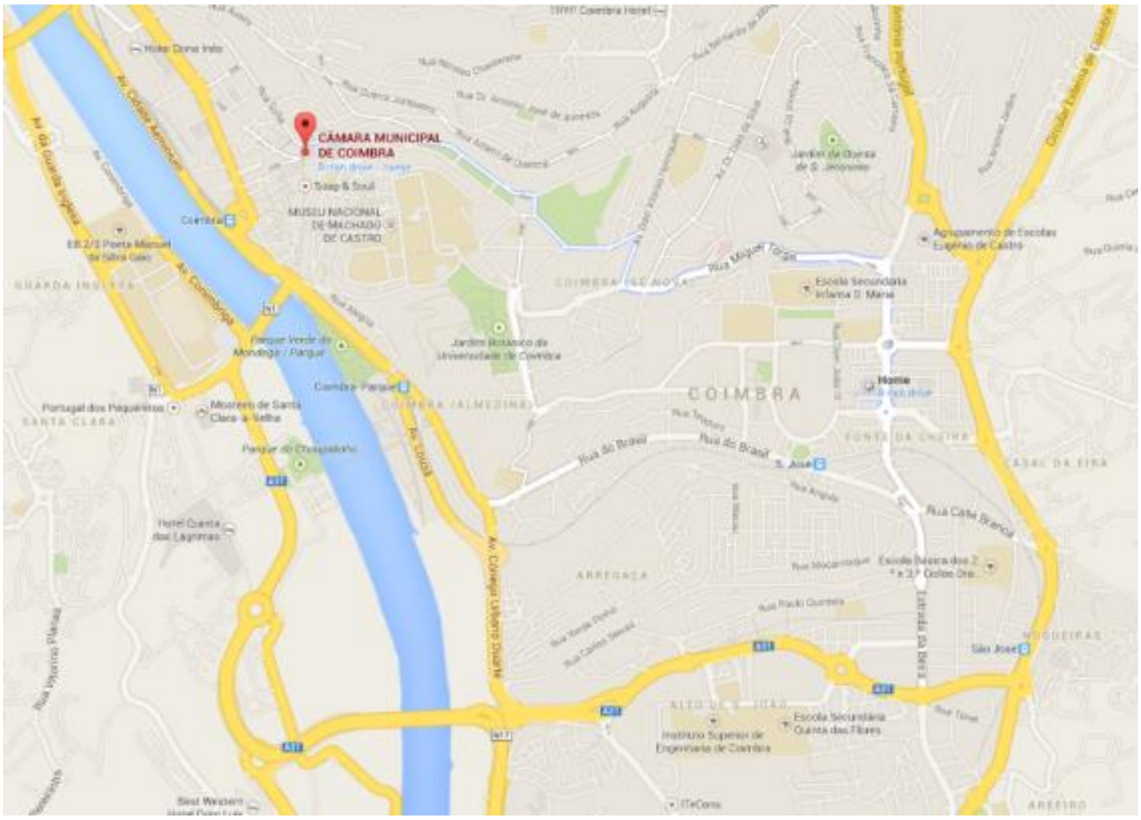


FIGURE 82: LOCATION IN THE CITY (MAP)

One video presenting the building is available at https://www.youtube.com/watch?v=IrsS95cpta4

Coimbra - part of the historic city centre, older University buildings and other urban structures - was inscribed on the World Heritage List of UNESCO (22/06/2013). The Property inscribed is called University of Coimbra — Alta and Sofia (http://worldheritage.uc.pt/). It is composed of a set of buildings whose history has been associated to the academic institution, either through participation in the process of knowledge production and dissemination, or through contribution to the creation of unique cultural and identitarian traditions. The Coimbra Town Hall is included in this area and therefore the building is protected.

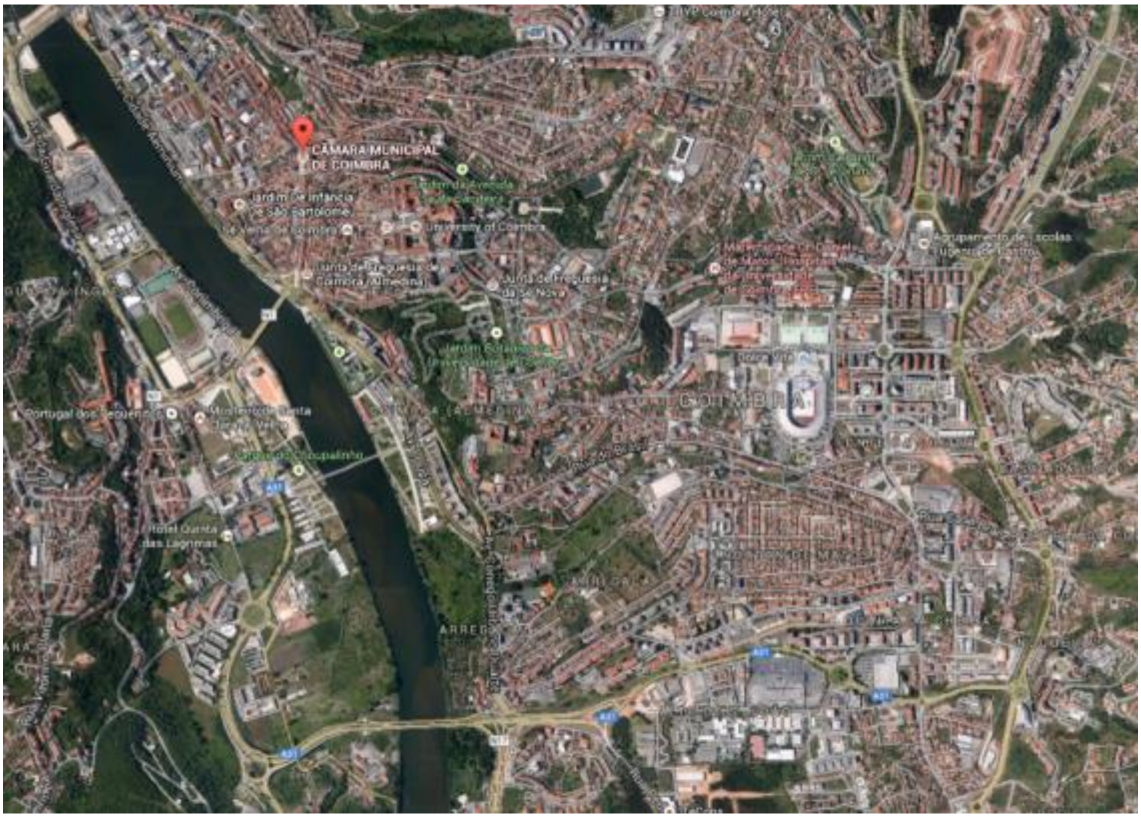


FIGURE 83: LOCATION IN THE CITY (AERIAL VIEW)

9.2. Shape and Orientation

Figure 84 presents the plan view and Figure 85 presents the aerial view of the building. The building has a maximum dimension of 45.6 x 70.6 m, constituted by two areas with 45.6 x 41.65 m and 20.65 x 28.95 m.

The building has 3 floors and 2 intermediate floors. The elevations plan is presented in Figure 86.

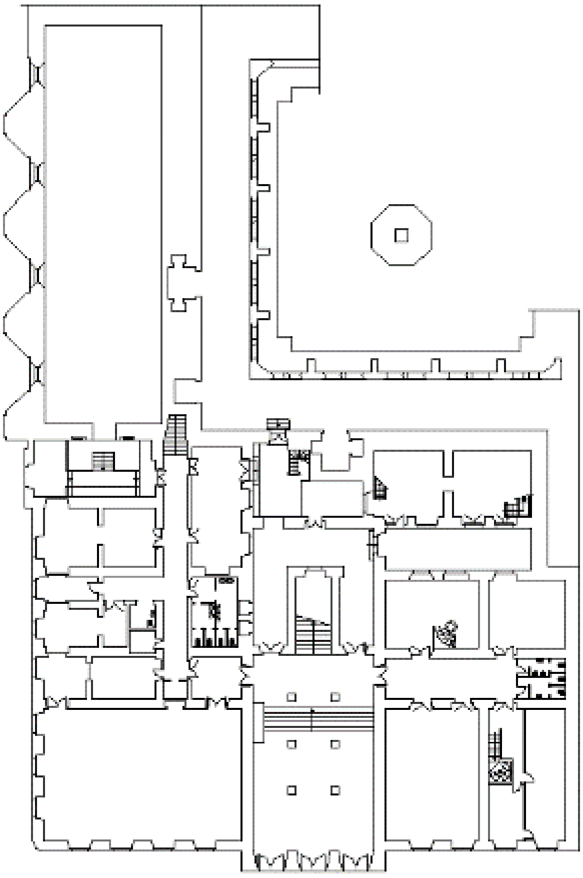


FIGURE 84: PLAN VIEW

FIGURE 85: AERIAL VIEW

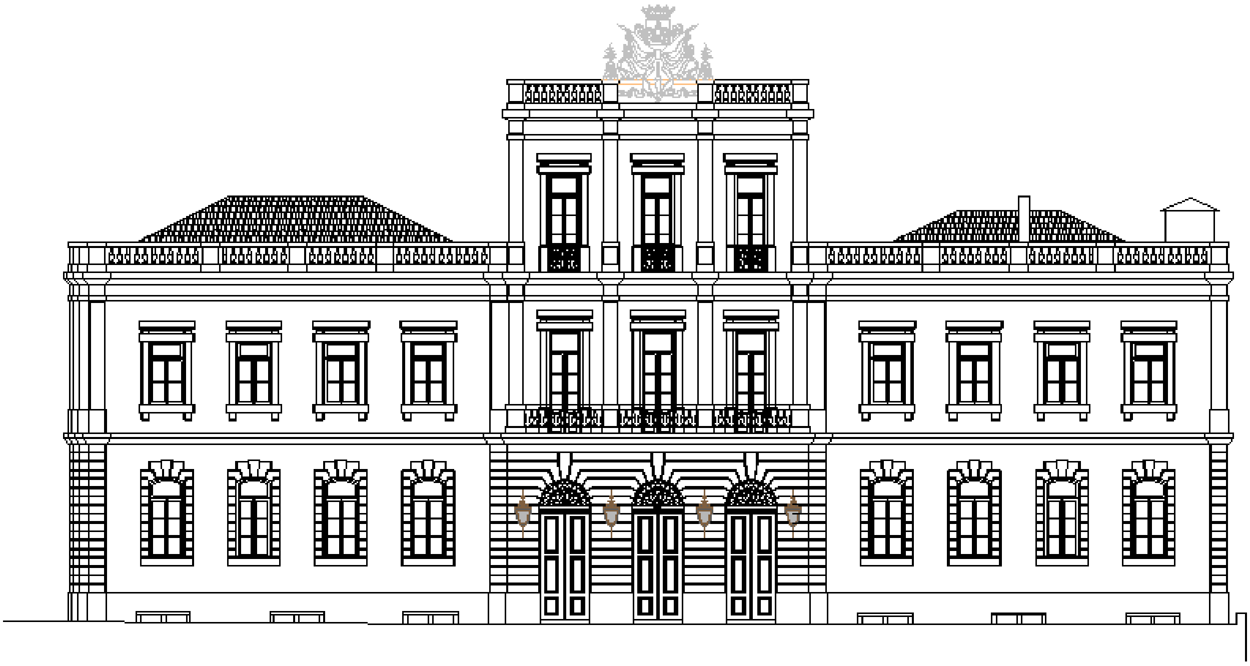


FIGURE 86: ELEVATION PLAN

As can be seen in Figure 87 the building is oriented with an axis of 10º, with the main façade oriented to West.

FIGURE 87: ORIENTATION OF THE MAIN FAÇADE

9.3. Area and Volume

The building has total area of about 5,880 m^2 with a total used surface of about 3,711 m^2 and a volume of 40,575 m^3.

As can be seen in Figure 5 the roof is made of ceramic tile and has a surface of 1,974 m^2.

However, it is planned a renovation of the roof with the following components:

- Wood panel (Oriented Strand Board) with 12 mm of thickness, used as base to the insulation;
- Thermo-acoustic insulation, constituted by sheets of extruded polystyrene with 60 mm of thickness;
- New ceramic roof.

9.4. Current Use

As already mentioned the building is used as the town hall of the Municipality of Coimbra. Therefore, the building is mainly constituted by offices (total of 3,395.8 m^2) and storage areas (total of 315.2 m^2). Table 93 presents the several rooms (identified in Figure 88 to Figure 92) and the respective use.

The building usually has occupation between 7h30 and 19h30 (Monday to Friday). However, the public only have access between 9h00 and 17h00. The building has 220 employees and is visited by more than 25,000 users/year.

TABLE 93: USE OF THE DIFFERENT ROOMS

Room	Floor	Use
1	0	Town Hall
2	0	DPGU[7]
3	0	DRM[8] Office
4	0	DSI
5	0	DSI
6	0	Atrium
7	0	Office
8	0	Reprography
9	0	WC
10	0	Engine Room
11	0	WC
12	0	DRM Office
13	0	DRM Office
14	0	Lift
15	0	DPA

Room	Floor	Use
54	1	Office
55	1	Office
56	1	Lift
57	1	Office
58	1	Office
59	1	Office
60	1	WC
61	1	Hall of the Municipal Council
62	1	Meeting Room
63	1	Office of the President
64	1	Waiting room
65	1	Office
66	1	Office
67	1	Office
68	1	Office

[7] DPGU – Department of Planning and Urban Management
[8] DRM – Department of Relationship with the Citizen

16	0	General Treasury
17	0	WC
18	0	WC
19	0	DRM – Public Service
20	0	Accounting and Finance Division
21	0	Notary
22	0	Notary
23	0-1	Not used
24	0-1	Not used
25	0-1	Data Centre
26	0-1	Not used
27	0-1	DSI[9]
28	0-1	Not used
29	0-1	Atrium
30	0-1	DPA[10]
31	0-1	Storage
32	0-1	Office
33	0-1	Office
34	0-1	Not used
35	0-1	Office
36	0-1	Not used
37	1	Cloisters
38	1	Cloisters
39	1	Office
40	1	WC
41	1	Office DPGU
42	1	Office DPGU
43	1	Atrium
44	1	Office
45	1	Office
46	1	Office
47	1	Office
48	1	Atrium
49	1	Atrium
50	1	Office
51	1	Office DPGU
52	1	Office
53	1	Office of the Municipal Council

69	1	Office
70	1-2	Office DPGU
71	1-2	Office DPGU
72	1-2	Office DPGU
73	1-2	Office DPGU
74	1-2	Office DPGU
75	1-2	Office DPGU
76	1-2	Office DPGU
77	1-2	Office DPGU
78	1-2	Office DPGU
79	1-2	Office DPGU
80	1-2	Office DPGU
81	1-2	Office DPGU
82	1-2	Office DPGU
83	1-2	Office DPGU
84	1-2	Office DPGU
85	1-2	Office DPGU
86	1-2	Storage DPGU
87	1-2	Storage DPGU
88	1-2	WC
89	1-2	Office
90	1-2	Office
91	1-2	Office DPC[11]
92	1-2	Office DPC
93	1-2	Office DPC
94	1-2	Not used
95	1-2	Office DPC
96	1-2	Not used
97	1-2	Office
98	1-2	Office
99	1-2	WC
100	1-2	Not used
101	2	Hall
102	2	WC
103	2	Office
104	2	Office
105	2	Office
106	2	Office

[9] DSI – Department of Information Systems
[10] DPA – Department of Patrimony and Procurement
[11] DPC –Department of Planning and Control

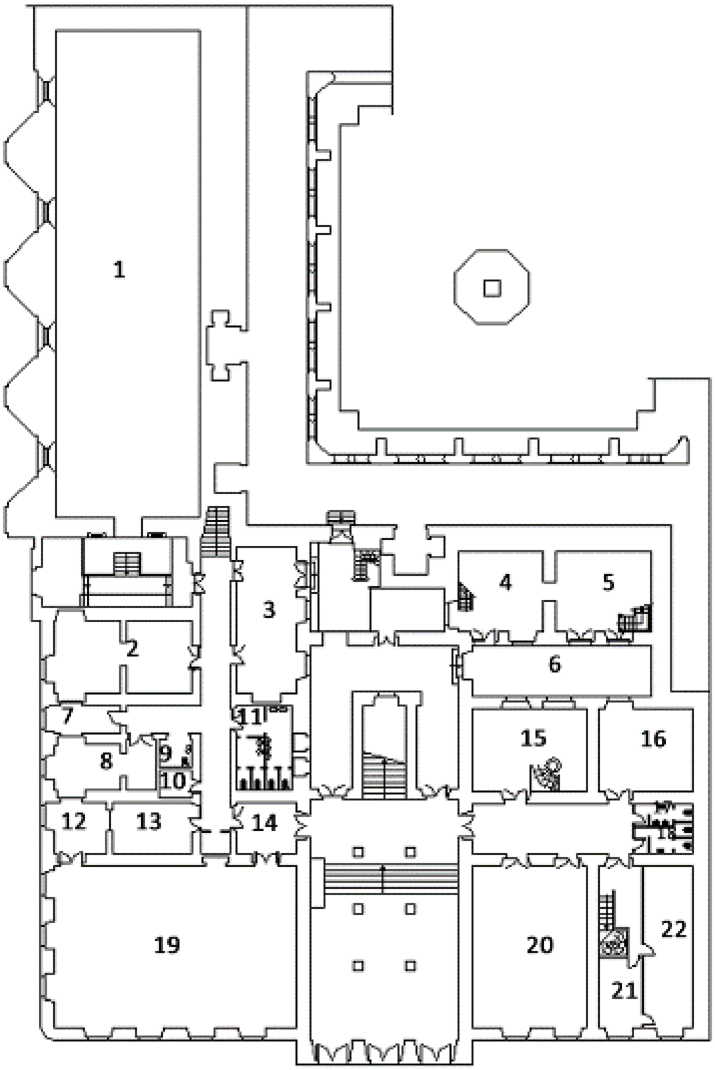


FIGURE 88: ROOMS USE IN FLOOR 0

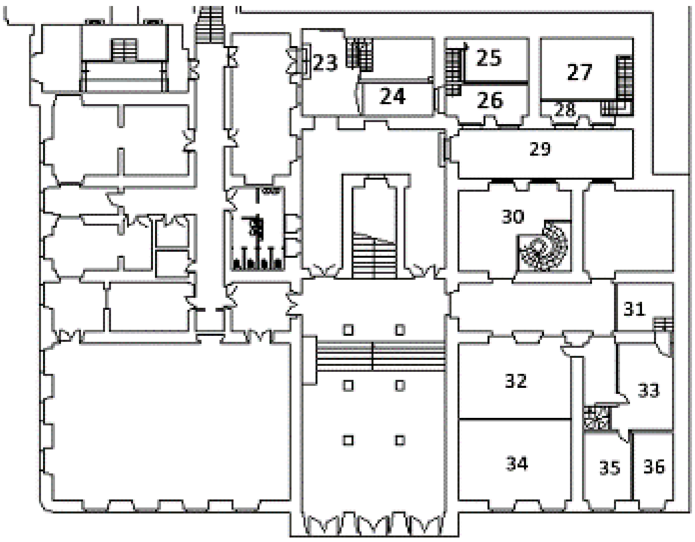


FIGURE 89: ROOMS USE IN THE INTERMEDIATE FLOOR BETWEEN FLOOR 0 AND 1

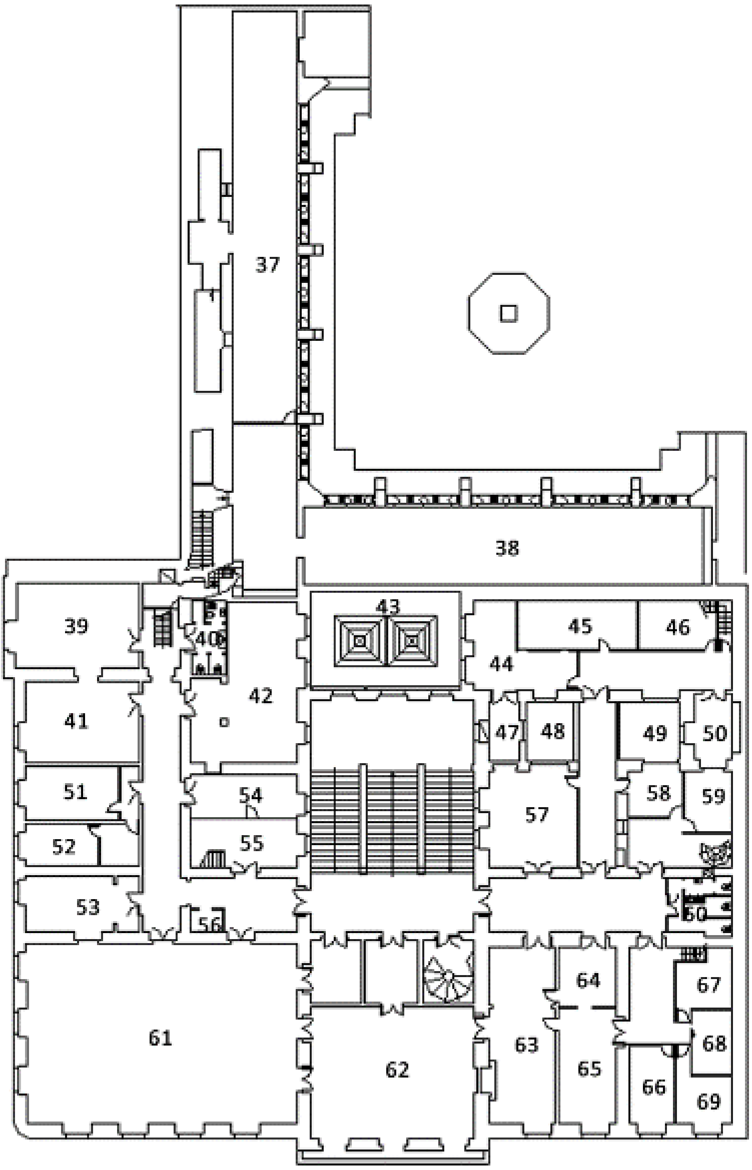


FIGURE 90: ROOMS USE IN FLOOR 1

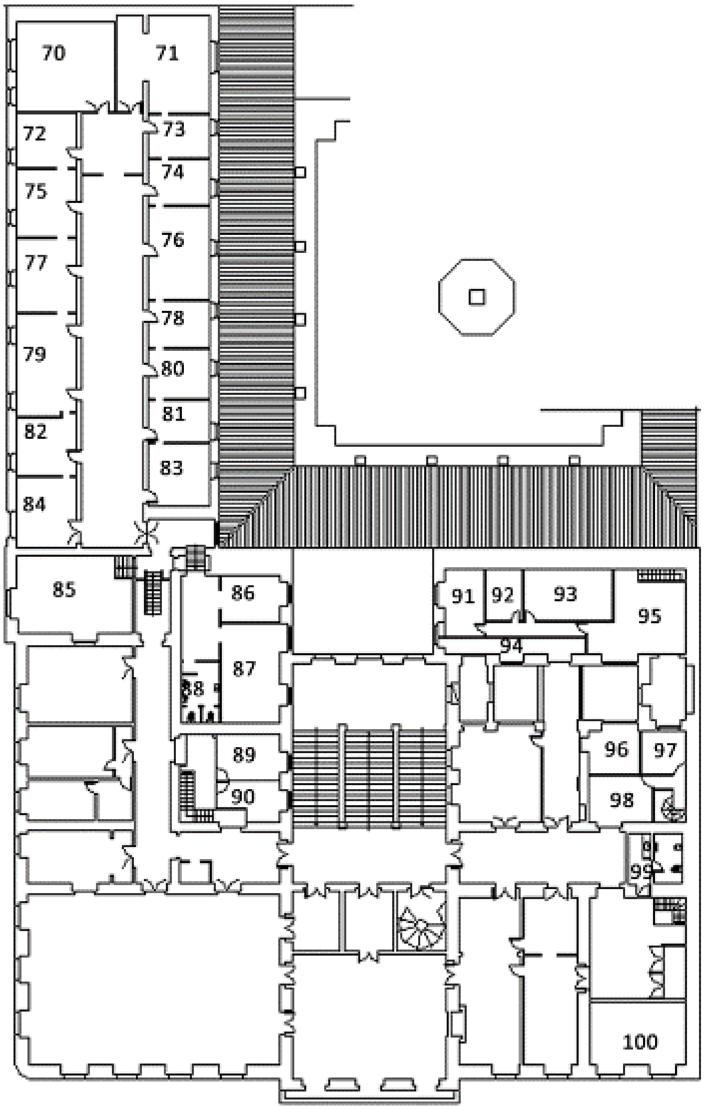


FIGURE 91: ROOMS USE IN THE INTERMEDIATE FLOOR BETWEEN FLOOR 1 AND 2

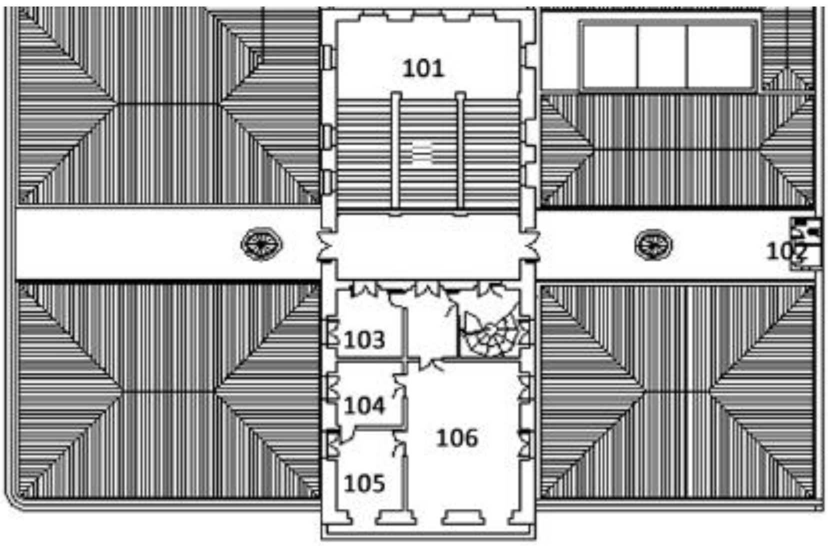


FIGURE 92: ROOMS USE IN FLOOR 2

10. Current Building Conditions

10.1. Constructive Building Characteristics

10.1.1. Envelope Elements

The walls of the front have a total surface of 751 m^2, of which 89 m^2 is transparent (11.9%). The lateral walls on the left has a total surface 1,234 m^2, of which 113 m^2 is transparent (9.1%).The back and lateral on the right of the building are connected with other buildings, excepting a small area which have an interior garden. The external walls are made of stone masonry and have a thickness of 90 to 145 cm.

Table 94 presents the considered heat loss for transmission to the outside in the envelope.

TABLE 94: HEAT LOSS FOR TRANSMISSION TO THE OUTSIDE IN THE ENVELOPE

Structure	Orient.	A	U	Abs.	A.U.A.Rse	U.A.
		m^2	W/m^2 ºC	α	W/ ºC	W/ ºC
Wall - Lateral	N	1,239.00	0.29	0.6	8.62	359.3
Wall - Front	W	751.24	0.29	0.6	5.23	217.9
Wall - Lateral	S	424.83	0.29	0.6	2.96	121.2
Wall - Back	E	187.43	0.29	0.6	1.30	54.4
Roof	-	1,974.00	0.50	0.4	15.79	987.0

10.1.2. Windows

All the windows and balcony doors are of single glazing with wood frames.

In the front there are the following windows:

- 8 operable of 1.4 x 3.4 m
- 8 operable of 1.4 x 2.2 m
- 3 operable of 1.4 x 2.6 m
- 8 balcony doors of 1.4 x 3.7 m

In the lateral on the left of the building there are the following windows:

- 4 fixed of 1.2 x 5.3 m
- 7 operable of 1.4 x 3.4 m
- 7 operable of 1.4 x 2.2 m
- 2 operable of 1.6 x 2.8 m
- 7 operable of 0.9 x 1.2 m
- 7 operable of 2.0 x 2.2 m
- 3 operable of 1.0 x 1.4 m
- 3 operable of 1.3 x 2.0 m

There are also the following windows directed to the interior garden:

- 7 operable of 0.9 x 1.2 m
- 1 operable of 2.0 x 2.2 m
- 3 operable of 1.3 x 4.5 m
- 1 operable of 1.3 x 3.8 m

- 1 operable of 1.3 x 3.4 m
- 1 operable of 1.3 x 4.9 m
- 1 operable of 1.3 x 4.7 m
- 1 operable of 1.3 x 4.5 m
- 1 operable of 1.3 x 3.1 m
- 1 operable of 1.3 x 3.0 m

In the front there are 3 wood doors of 2.0 x 4.5 m and in the lateral there is one wood door of 1.6 x 4.2 m.The windows have internal wooden shutters and semi-transparent cloth curtains. Additionally, some shading is also ensured by other buildings.

Table 95 presents the considered heat loss for transmission to the outside in windows.

TABLE 95: HEAT LOSS FOR TRANSMISSION TO THE OUTSIDE IN WINDOWS

Structure	Orient.	A	U	F_g	A_{eq}	U.A.
		m^2	W/m² ºC		m^2	W/ ºC
Windows - Lateral	N	113.24	5.7	0.84	95.1	645.5
Windows - Front	W	89.18	5.7	0.84	74.9	508.3
Windows - Back	S	38.81	5.7	0.84	32.6	221.2
Windows - Back	E	26.28	5.7	0.84	22.1	149.8

10.1.3. Airtightness and Pathologies

A previous study analysed the envelope with thermal imaging with an external air temperature of 6ºC.

Figure 93 presents the general image of the thermal performance of the envelope. As can be seen the walls present a good thermal performance.

FIGURE 93: GENERAL IMAGE OF THE THERMAL PERFORMANCE OF THE ENVELOPE

Figure 94 presents the thermal losses in the windows. The windows, with single glazing with wood frames, present insulation problems, aggravated by aging, contributing to high heat losses during winter.

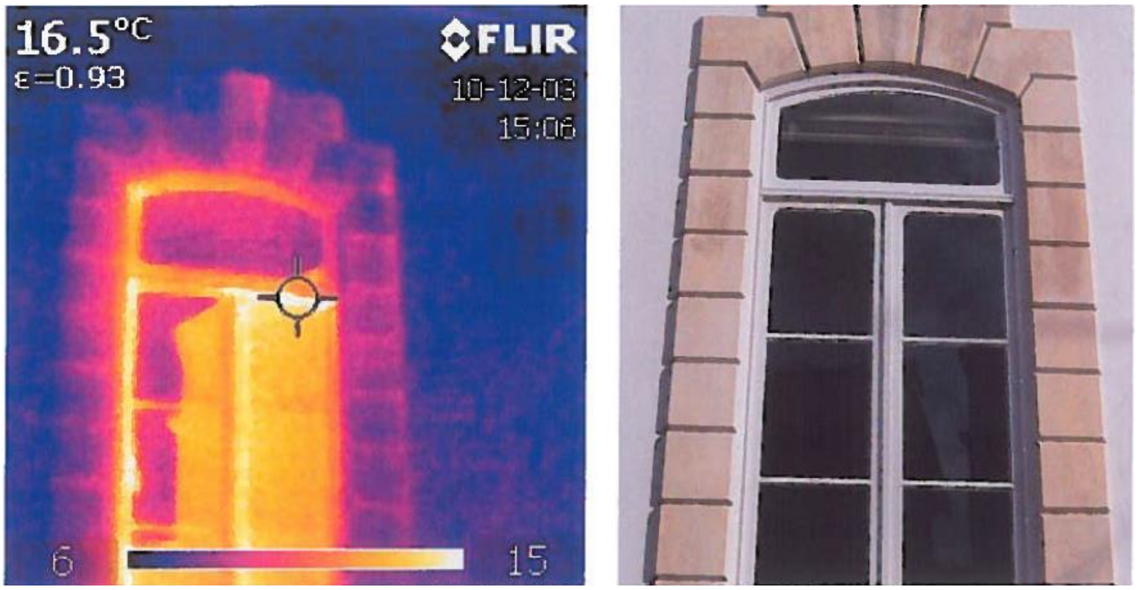


FIGURE 94: THERMAL LOSSES IN THE WINDOWS

Figure 95 presents the thermal losses due to the thermal bridges near to windows, which contribute to increase the losses.

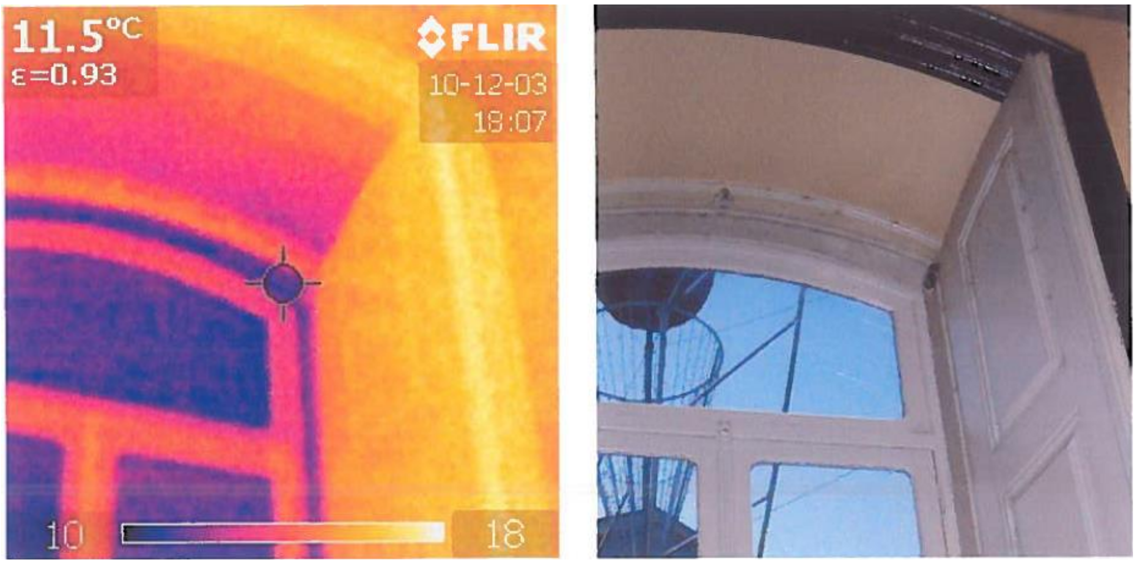


FIGURE 95: THERMAL LOSSES DUE TO THE THERMAL BRIDGES NEAR TO WINDOWS

Some characteristics of the building contribute to a bad thermal performance:

- The orientation is not ideal, requiring additional energy consumption with heating during the winter (mainly in the north areas) and with cooling during the summer (mainly in the west areas without any direct protection from the direct radiation).

- The walls with high thermal inertia and large ceiling height provide advantages during the summer, but disadvantages during winter, since the building does not have users in the night period and weekends which leads to a significant decrease in temperature.
- The windows have a low level of air-tightness, resulting in a high level of air infiltration, which is not controllable and undesirable especially during the winter.

The building does not present major pathologies, such as condensations or mould growth.

10.2. Energy Systems

10.2.1. Lighting

The lighting is ensured by several different types of lamps and luminaires (Figure 96), including fluorescent linear T8 and T5 lamps, several types of compact fluorescent lamps, incandescent lamps, halogen spots and projectors and metal halide lamps.

FIGURE 96: EXAMPLES OF LUMINAIRES USED IN THE BUILDING

Table 55 presents the types and quantities of lamps, as well as the total installed power.

TABLE 96: TYPES AND QUANTITIES OF LAMPS

Lamp Type	Quantity n	Power W
Compact Fluorescent E27	139	2,502
Compact Fluorescent E14	156	1,404
Compact Fluorescent 2G11	182	4,914
Incandescent	34	2,040
Fluorescent Linear T8 F30	6	70
Fluorescent Linear T8 F60	69	1,615
Fluorescent Linear T8 F120	242	11,326
Fluorescent Linear T8 F150	195	13,202
Fluorescent Linear T5 F120	20	600
Fluorescent Linear T5 F150	56	3,136
Halogen Spot	4	200
Halogen Projector	22	4,400
Halogen Projector	18	9,000
Metal Halide	10	5,000
Total	**1,153**	**58,008**

The control of the lighting is mainly ensured locally without any automatic control, which allows that some lighting circuits remain turned on without being needed. In the case of the circulation areas, where usually there is enough natural lighting, the lamps are almost always turned on (Figure 97).

FIGURE 97: LIGHTING IN CIRCULATION AREAS

10.2.2. HVAC

The HVAC is ensured with several heat pumps, which were being installed gradually. Therefore, there are several equipment with different characteristics and performance. In total, there are 8 multi-split units and 21 mono-split units (Figure 98). Almost all the areas of permanent use have HVAC systems. The control of the HVAC systems is ensured locally with units of individual control.

FIGURE 98: MULTI-SPLIT (LEFT) AND MONO-SPLIT (RIGHT) SYSTEMS.

Table 97 presents the mono-split systems and Table 98 the multi-split systems installed in the building.

TABLE 97: MONO-SPLIT HVAC SYSTEMS

Brand	Model	$P_{cooling}$ (kW)	$P_{heating}$ (kW)	Quantity
FNAC	C09 F-L	2.58	3.52	1
FNAC	C17 F-L	4.92	3.02	1
Fuji	RO-93RN	3.31	3.98	2
Fuji	RO-93RN	2.64	3.34	6
Mitsubishi	FDFL 254 HENZ	5.60	6.30	1
Mitsubishi	SCT 323 HENF-L	1.29	1.37	2
Olimpia	MATRIC–U2108hB	1.30	1.30	1
Sanyo	SAP-CR184EH	5.15	5.70	2
Sanyo	SAP-K76GF55	2.15	2.40	1
Sanyo	SPW-C253GH8	2.63	2.74	3
Tensai	PTAH-9001	2.64	3.22	1
Total		**62.42**	**70.12**	**21**

TABLE 98: MULTI-SPLIT HVAC SYSTEMS

Brand	Model	$P_{cooling}$ (kW)	$P_{heating}$ (kW)	Quantity
Daikin	RSXY – 10K7W1	28.0	31.5	6
Mitsubishi	FDCA 140HKXES4	14.6	16.6	1
Mitsubishi	FDCA 280HKXE4	28.0	31.5	1
Total		**210.6**	**237.1**	**8**

The HVAC systems have a total power of 273 kW in cooling and 307 kW in heating. Additionally, in some rooms, there are electric oil-filled radiators and foot warmers. The existence of such equipment indicates that the installed heating is not enough to ensure the desired comfort levels in all rooms.

The air circulation and renewal is ensured naturally through the doors and windows. There are only 2 systems of forced ventilation in specific rooms:

- Hall of the Municipal Council (area 61) – system of insufflation and extraction with heating resistors with 1.5 kW.

- Reprography (area 8) – system of air renewal with heat recovery (Mitsubishi LGH-25RX4-E) with 140 W.

Both systems are just used in very cold days.

10.2.3. ICT

ICT (Information and Communications Technologies) is considered not only the communication devices but also other electronic devices, such as computers, printers, etc. The main ICT systems receive power from 3 groups of UPS, located in different rooms:

- group with 2 UPS CHLORIDE Linear Plus (2 x 10 kVA);
- group with 2 UPS CLORIDE Power El (2 x 6 kVA);
- 1 UPS Merlin Gerin (7 kVA).

10.2.4. Others

It was considered as "other" the lift and other small appliances connected to plugs such as individual electric heaters, vending machines, photocopier machines, computers and printers (when not connected to the UPSs), etc. The lift (manufactured by OTIS) is hydraulic and has capacity for 630 kg (8 users) and a power of 11 kW.

10.3. Energy Consumption and Energy Generation

10.3.1. Electricity Consumption

The building receives electricity in Low Voltage. The characteristics of the contract are presented in Table 99.

TABLE 99: CHARACTERISTICS OF THE ELECTRICITY CONTRACT

Voltage Level	Special Low-Voltage
Contracted Power	148 kW
Tariff Option	Energy + Grid + SLV
Cycle	Diary

To a diary cycle in Special Low-Voltage there are 4 different tariff periods, which are presented in Table 100.

TABLE 100: SCHEDULE OF THE TARIFF PERIODS

Period	Winter	Summer
On-Peak	09h00 – 10h30 18h00 – 20h30	10h30 – 13h00 19h30 – 21h00
Mid-Peak	08h00 – 09h00 10h30 – 18h00 20h30 – 22h00	08h00 – 10h30 13h00 – 19h30 21h00 – 22h00

Normal Off-Peak	22h00 – 02h00 06h00 – 08h00	22h00 – 02h00 06h00 – 08h00
Super Off-Peak	02h00 – 06h00	02h00 – 06h00

In 2013 the building had an electricity consumption of about 305 MWh and an associated cost of about 60 k€. Table 101 presents the evolution of the consumption and costs between 2011 and 2013. As can be seen the consumption have been decreasing during the last 2 years.

TABLE 101: EVOLUTION OF THE CONSUMPTION AND COSTS DURING THE LAST 3 YEARS

Year	Parameter	1st Q	2nd Q	3rd Q	4th Q	Total	Avg Day
2011	Consump. (kWh)	129,251.0	95,308.0	87,919.0	85,188.0	397,666.0	1089.5
	Cost € (w/ VAT)	17,046.8	11,870.1	10,797.3	12,016.0	51,730.3	141.7
2012	Consump. (kWh)	121,502.0	78,791.0	74,286.0	74,267.0	348,846.0	955.7
	Cost € (w/ VAT)	20,252.6	15,691.1	13,587.5	13,705.0	63,236.2	173.2
	Δ Cons. (kWh)	-7,749.0	-16,517.0	-13,633.0	-10,921.0	-48,820.0	-133.8
	Δ Consump. (%)	-6.00%	-17.33%	-15.51%	-12.82%	-12.28%	-12.28%
2013	Consump. (kWh)	94,254.0	66,652.0	70,415.0	73,786.0	305,107.0	835.9
	Cost € (w/ VAT)	21,017.0	12,304.9	12,872.8	13,363.0	59,557.7	163.2
	Δ Cons. (kWh)	-27,248.0	-12,139.0	-3,871.0	-481.0	-43,739.0	-119.8
	Δ Consump. (%)	-22.43%	-15.41%	-5.21%	-0.65%	-12.54%	-12.54%

Figure 99 and Figure 100 present the evolution of the monthly electricity consumption and costs between 2008 and 2013. As can be seen the different years present a similar variation of consumption between months, with a higher consumption during winter.

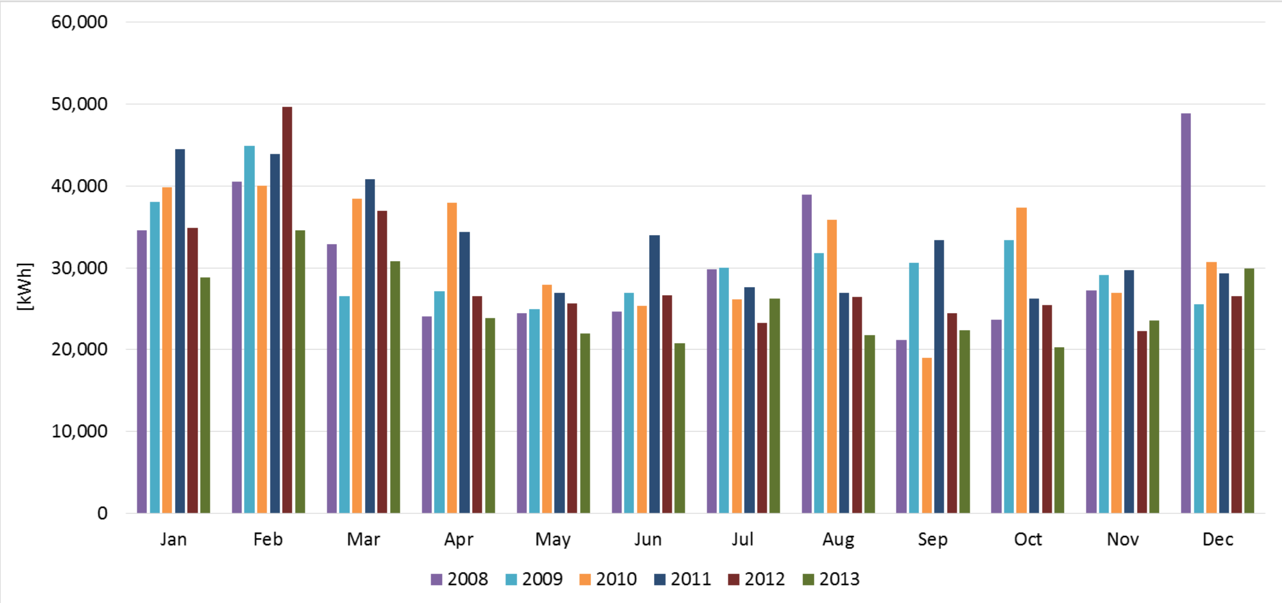


FIGURE 99: MONTHLY CONSUMPTION BETWEEN 2008 AND 2013

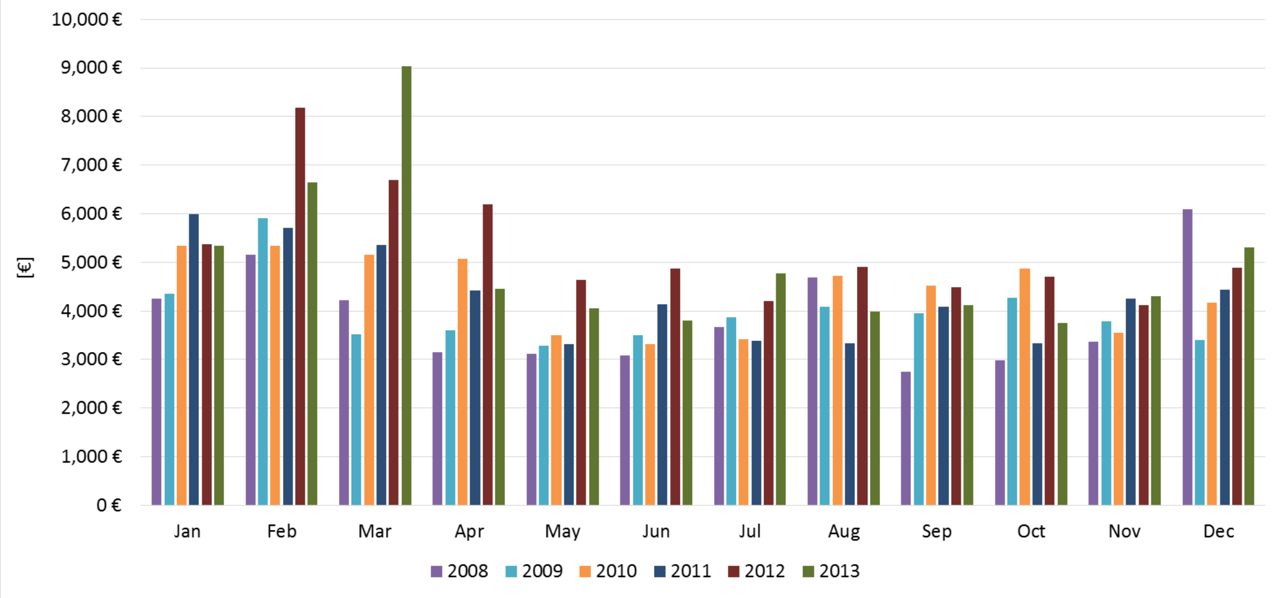


FIGURE 100: MONTHLY COSTS BETWEEN 2008 AND 2013

As can be seen in Figure 101 and Figure 102, the distribution between tariff periods does not present large variations between the different months, being in average: 18.6% in on-peak; 53.4% in mid-peak; 19.4% in normal off-peak and 8.5% in super off-peak.

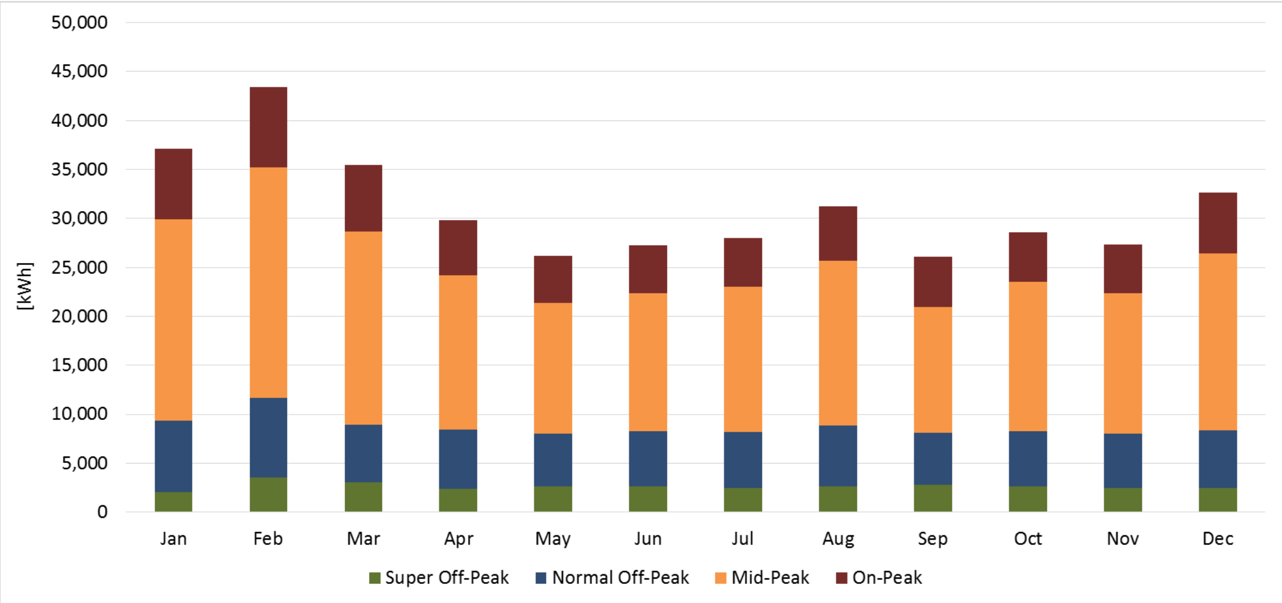


FIGURE 101: MONTHLY DISAGGREGATION BETWEEN TARIFF PERIODS IN THE AVERAGE 2008-2013 (KWH)

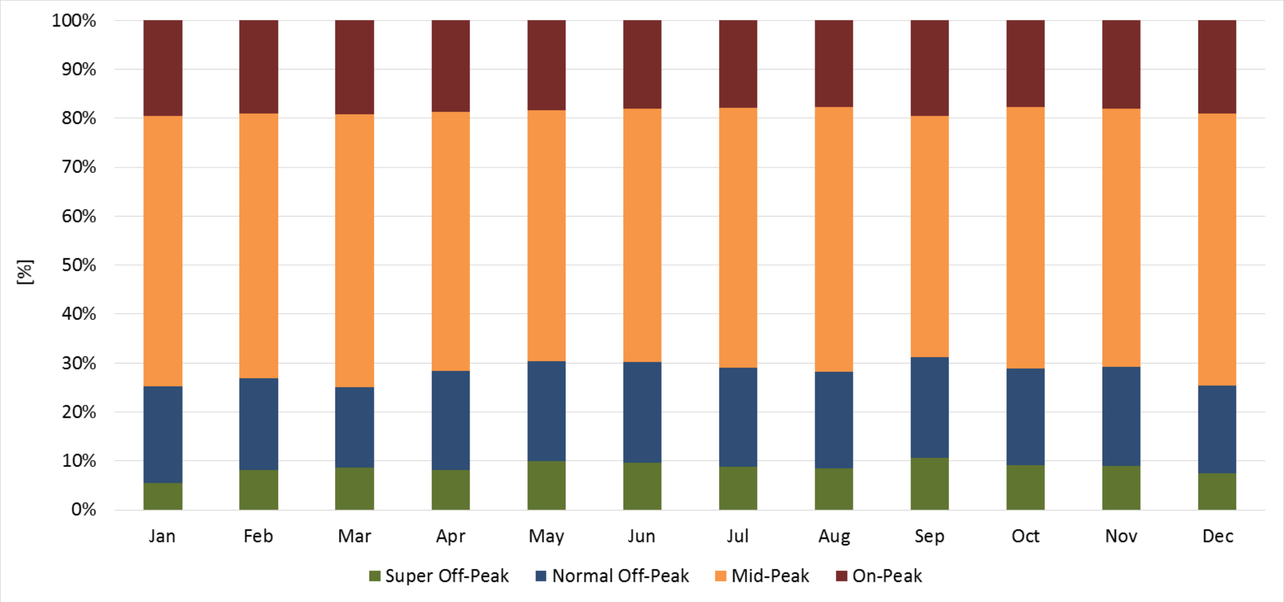


FIGURE 102: MONTHLY DISAGGREGATION BETWEEN TARIFF PERIODS IN THE AVERAGE 2008-2013 (%)

Figure 103 presents the consumption profile during 7 days (from Saturday to Friday) in a cold week (Wednesday was a Holiday). As can be seen the baseload consumption is high and similar between night periods and weekends.

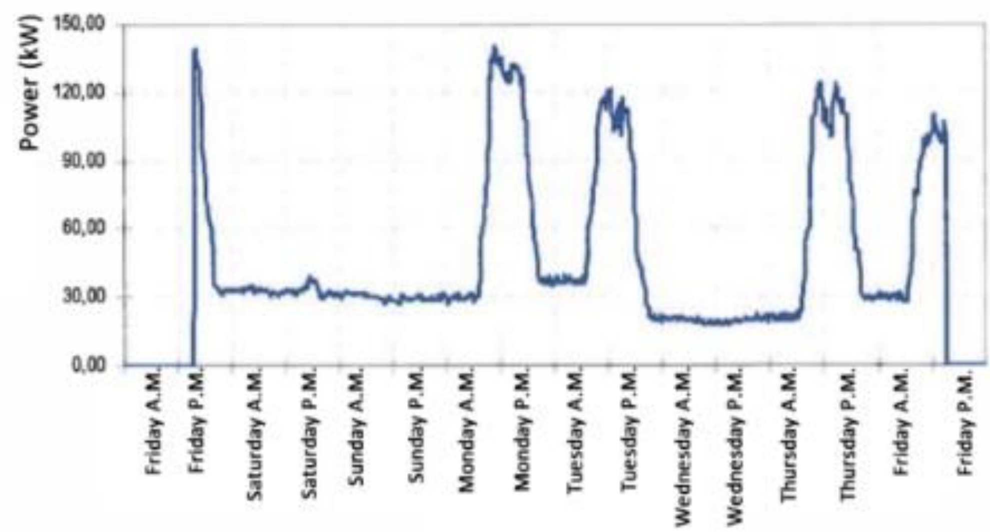


FIGURE 103: CONSUMPTION PROFILE IN THE MAIN ELECTRICAL BOARD

Figure 104 presents the disaggregation of electricity consumption between uses, based on the data available from consumption monitoring and use of electrical equipment. The consumption is mainly divided between 3 major uses (without a major difference between them): lighting, HVAC and ICT.

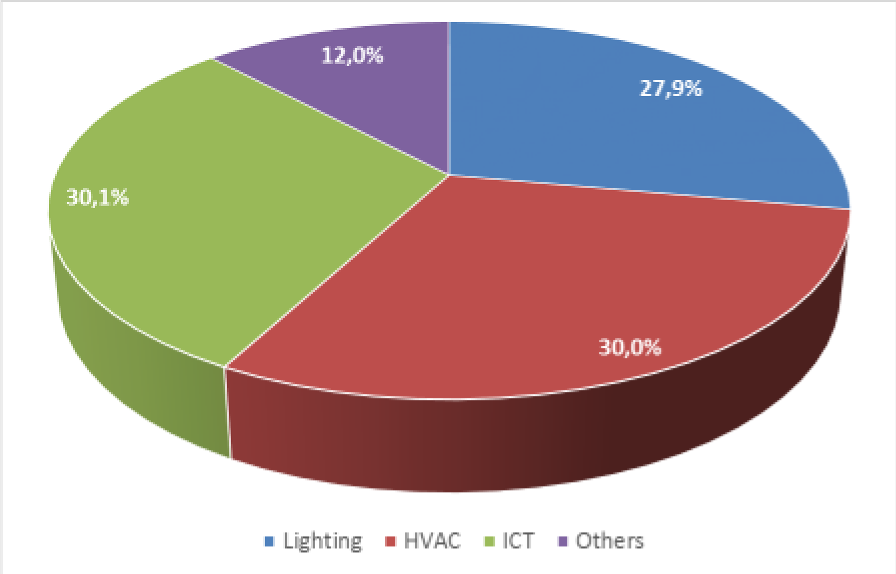


FIGURE 104: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES

10.3.2. Gas/Oil Consumption

The building does not have any gas or oil consumption.

10.3.3. Renewable Energy Sources

The building does not have any renewable energy source.

10.3.4. Other Generation

The building does not have any other source of generation.

10.3.5. Final Energy Consumption and CO_2 Emissions

During 2013 the buildings had an electricity consumption of 305,107 kWh (Table 102). The building does not have consumption of gas.

TABLE 102: ENERGY CONSUMPTION IN 2013

	Consumption kWh
Electricity	305,107
Gas	0

Table 103 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 - 2.5 (standard value approved for Portugal);
- natural gas to primary energy - 1.0 (standard value);
- electricity to CO_2 emissions - 139.89 g/kWh (average emissions associated with the electricity consumed in Portugal during 2013);
- natural gas to CO_2 emissions - 202 g/kWh (standard value).

TABLE 103: ENERGY PARAMETERS

	Final Energy kWh	Energy Dens. kWh/m^2	Primary Energy kWh	CO_2 Emissions kg CO_2 /kWh
Electricity	305,107	51.9	762,767.5	42,681.4
Gas	0	0	0	0
Generation	0	0	0	0
Total	305,107	51.9	762,767.5	42,681.4

11. Renovation Scheme

11.1. Aim of the Renovation Plan

The objective of the renovation plan 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.

The following global constraints were taken into account in the design of the renovation plan:

- Since the building is part of the property "University of Coimbra — Alta and Sofia" inscribed on the World Heritage List of UNESCO several strong restrictions are applied in the renovation of such building due to the protection rules, since it is not possible to implement any change in the building envelope that causes a visual impact. Therefore, renovation options with a high visual impact is avoided in the renovation plan.
- The building has an intensive utilization, receiving a large number of visitors, and is the working place for a large number of Municipal employees and such activities cannot be interrupted since it is not easy to temporarily move the services to another building. Therefore, renovation options requiring major construction works, incompatible with the normal activities of the building, were avoided in the renovation plan.

11.2. Energy Demand Reduction

11.2.1. Opaque Envelope

Regarding the insulation, as previously explained the walls present a good thermal performance. The roof is to undergo an already planned renovation soon. Therefore, the improvement of the opaque envelope was not considered in the renovation plan.

11.2.2. Openings

The windows present high thermal losses. However, since the building is part of the property "University of Coimbra — Alta and Sofia" inscribed on the World Heritage List of UNESCO several strong restrictions are applied in the renovation of such building due to the protection rules and it is not possible to implement any change in the building envelope that causes a visual impact. Therefore, it is not possible to replace the windows by double glazed windows using standard solutions, since the original frame must be maintained (the usual solution is to implement other window in the interior). Since these frames have to be specifically designed to this building, this cannot be ensured with standard solutions available in the market, and would have a high cost. Therefore, the improvement of openings was not considered in the renovation plan.

11.3. Energy Systems

11.3.1. Lighting System

As previously presented the actual lighting system is constituted by several different types of lamps and luminaires, including fluorescent linear T8 and T5 lamps, several types of compact fluorescent lamps, incandescent lamps, halogen spots and projectors and metal halide lamps (Table 104).

Regarding the retrofit of the lighting system 2 scenarios were considered:

- Scenario 1 - Replacement of all T8 lamps with electromagnetic ballast by T5 lamps with electronic; and replacement of the incandescent lamps by CFLs
- Scenario 2 - Replacement of all lamps by LEDs.

TABLE 104: TYPES AND QUANTITIES OF LAMPS

Lamp Type	Quantity n	Power W
Compact Fluorescent E27	139	2,502
Compact Fluorescent E14	156	1,404
Compact Fluorescent 2G11	182	4,914
Incandescent	34	2,040
Fluorescent Linear T8 F30	6	70
Fluorescent Linear T8 F60	69	1,615
Fluorescent Linear T8 F120	242	11,326
Fluorescent Linear T8 F150	195	13,202
Fluorescent Linear T5 F120	20	600
Fluorescent Linear T5 F150	56	3,136
Halogen Spot	4	200
Halogen Projector	22	4,400
Halogen Projector	18	9,000
Metal Halide	10	5,000
Total	**1,153**	**58,008**

In scenario 1, 546 lamps and 512 ballasts have to be replaced. Table 105 presents the lamps and ballasts to be installed and Table 106 shows the new distribution of lamps. As can be seen, the total power decreases to 49775 W (reduction of 14.2%).

TABLE 105: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN SCENARIO 1

Lamp Type	Quantity n	Lamp W	Lamp+Ballast W
Fluorescent Linear T5 F150	195	49	56
Fluorescent Linear T5 F120	242	28	30
Fluorescent Linear T5 F60	69	14	17
Fluorescent Linear T5 F30	6	7	9
Compact Fluorescent E27	34	18	-

TABLE 106: TYPES AND QUANTITIES OF LAMPS CONSIDERED IN SCENARIO 1

Lamp Type	Quantity n	Power W
Compact Fluorescent E27	173	3,114
Compact Fluorescent E14	156	1,404
Compact Fluorescent 2G11	182	4,914
Fluorescent Linear T5 F30	6	54
Fluorescent Linear T5 F60	69	1,173
Fluorescent Linear T5 F120	89	1,773
Fluorescent Linear T5 F150	251	14,056
Halogen Spot	4	200
Halogen Projector	22	4,400
Halogen Projector	18	9,000
Metal Halide	10	5,000
Total	**1,153**	**49,775**

In scenario 2, 1153 lamps have to be replaced. Table 107 presents the lamps to be installed and Table 108 shows the new distribution of lamps. As can be seen, the total power decreases to 24,000 W (reduction of 58.6%).

TABLE 107: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN SCENARIO 2

Lamp Type	Quantity n	Lamp W
LED E27	173	9.5
LED E14	156	3
LED 2G11	182	18
LED Linear F30	6	6
LED Linear F60	69	10
LED Linear F120	262	20
LED Linear F150	251	24
LED Spot	4	5,5
LED Projector	22	100
LED Projector	18	200
LED Projector	10	80

TABLE 108: TYPES AND QUANTITIES OF LAMPS CONSIDERED IN SCENARIO 2

Lamp Type	Quantity n	Total Power W
LED E27	173	1,644
LED E14	156	468
LED 2G11	182	3,276
LED Linear F30	6	36
LED Linear F60	69	690
LED Linear F120	262	5,240
LED Linear F150	251	6,024
LED Spot	4	22
LED Projector	22	2,200
LED Projector	18	3,600
LED Projector	10	800
	1,153	**24,000**

Table 109 presents the yearly consumption with lighting in the different scenarios, as well as the percentage of achievable savings. Such energy consumptions were simulated considering the actual usage profile for each lamp type and room of the building. As can be seen, scenario 1 ensures 15.1% and scenario 2 ensures 57% of energy savings.

TABLE 109: YEARLY CONSUMPTION WITH LIGHTING IN THE 2 SCENARIOS

	Actual	Scenario 1	Scenario 2
Consumption (kWh)	85,818	72,880	36,901
Savings (kWh)	-	12,938	48,916
Savings (%)	-	15.1%	57.0%

11.3.2. HVAC System

As previously presented the HVAC system is constituted by 8 multi-split units and 21 mono-split units with a total cooling power of 273.02 kW (210.6 kW in multi-split and 62.42 kW in mono-split systems). Most of the systems are old and do not present technical data to characterize its efficiency. Therefore, it was considered an average EER of 2.0 and a COP of 2.2.

The replacement of mono-split systems by multi-split systems and the concentration of multi-split systems in less units was not considered, since the impact of the installation process on the building operation would be much higher. Therefore, it was always considered the replacement by systems of the same type, but with higher efficiency, keeping the same total power.

Table 110 presents the characteristics and distribution of mono-split systems considered in the renovation.

TABLE 110: TECHNICAL DATA OF THE NEW MONO-SPLIT SYSTEMS

P_{ind} (kW)	EER	COP	Quantity	P_{total} (kW)
1.3	9.1	5.2	3	3.9
2.5	9.1	5.2	12	30
3.5	8.9	5.1	2	7
5.2	6.1	3.8	4	20.8
	8.1	**4.7**	**21**	**61.7**

Table 111 presents the characteristics and distribution of multi-split systems considered in the renovation.

TABLE 111: TECHNICAL DATA OF THE NEW MULTI-SPLIT SYSTEMS

P_{ind} (kW)	EER	COP	Quantity	P_{total} (kW)
28	5.20	5.74	7	196.0
14.6	4.68	4.92	1	14.6
	5.16	**5.68**	**8**	**210.6**

Table 112 presents the yearly consumption with HVAC in the actual and retrofit scenarios. Such energy consumptions were simulated considering the actual usage profile and the change of COP/EER. As can be seen, the retrofit ensures about 63% of energy savings.

TABLE 112: YEARLY CONSUMPTION WITH THE HVAC SYSTEM

		Actual	Scenario 1
Mono	Consumption (kWh)	20,946	6,882
	Savings (kWh)	-	14,064
	Savings (%)	-	67.1%
Multi	Consumption (kWh)	70,670	27,362
	Savings (kWh)	-	43,308
	Savings (%)	-	61.3%
Total	Consumption (kWh)	91,616	34,244
	Savings (kWh)	-	57,372
	Savings (%)	-	62.6%

11.3.3. ICT and Others

ICT appliances (mainly PCs, monitors and printers) represent an important share of the consumption. Replacing the PC and monitors by laptops would save, in average, 60% of the energy (a laptop has an average power of 50 W whereas a PC with CRT monitor has an average power of 150 W and a PC with TFT monitor has an average power of 100 W).

However, the replacement of such appliances by new devices is not cost-effective just from the energy savings point of view due to the high cost of the equipment and therefore this is not considered in the renovation plan. However, in the regular replacement of ICT appliances it is recommended to install just ICT appliances with lower energy consumption.

From the energy savings point of view, the most cost-effective solution is the installation of devices to reduce the standby consumption of ICT appliances, the so called standby killers. However, the potential savings achieved with such devices do not depend on the technology, but on the users' behaviour and therefore a reliable assessment of savings is not possible. Therefore, such measure is not included in the renovation plan, due to the difficulty of assessment, its implementation is recommended.

The main ICT systems receive power from 3 groups of UPS with a total power of 39 kVA. Such UPS have a weighted efficiency of 92% and nowadays there are available in the market products with higher efficiency (weighted efficiency of 95% or higher). The replacement of a UPS before the end of its lifetime is not cost-effective. However, in the processes of renovation due to the end of lifetime or due to needed upgrades on the ICT system, such UPS should be replaced by high efficient UPS systems.

Table 113 presents the potential impact on the consumption with ICT achieve with the replacement of PCs and monitors and UPS. As can be seen, such replacement ensures about 53% of energy savings.

TABLE 113: YEARLY CONSUMPTION WITH ICT

		Actual	Scenario 1
PC+M.	Consumption (kWh)	76,041	30,416
	Savings (kWh)	-	45,625
	Savings (%)	-	60%
UPS	Consumption (kWh)	7,347	4,592
	Savings (kWh)	-	2,755
	Savings (%)	-	37.5%
Other	Consumption (kWh)	8,450	8,450
	Savings (kWh)	-	-
	Savings (%)	-	-
Total	Consumption (kWh)	91,837	43,457
	Savings (kWh)	-	48,380
	Savings (%)	-	52.7%

Regarding other loads, the main load is the lift. However, its use is low and therefore the replacement of such lifts by systems with higher efficiency is not cost-effective.

11.4. Renewable Energy Sources

11.4.1. PV Generation

Since the building is part of the property “University of Coimbra — Alta and Sofia” inscribed on the World Heritage List of UNESCO several strong restrictions are applied in the renovation of such building due to the protection rules, since it is not possible to implement any change in the building envelope able to cause any visual impact. Therefore it is not possible to install standard PV panels or wind power on the roof or facades. However, it is not possible to achieve a Zero Energy Building without generation and since there are no other available options, the use of PV power must be considered, being just considered options with a small visual impact.

Figure 105 shows the roof of the building. As can be seen it has an azimuth of -10º and there are roof surfaces oriented not only to South, but also to North, East and West. Due to the protection rules, the use of traditional PV panels was not considered due to its high visual impact. Therefore, it was considered the use of solar tiles, to replace the actual roof.

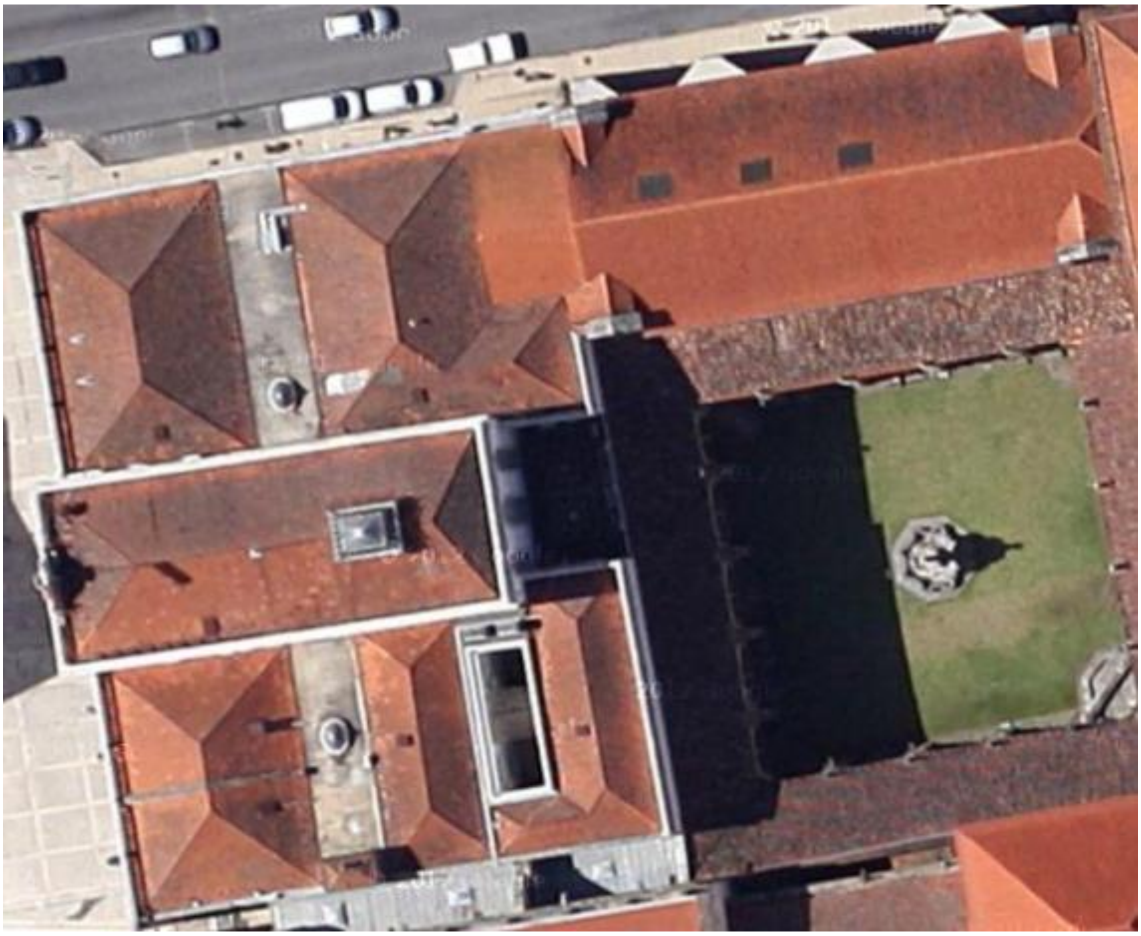


FIGURE 105: ROOF

As can be seen in Figure 106 (left), a solar roof has to be black. However, a margin can be keep in order to keep the original colour in the visible areas, as can be seen in Figure 106 (right). There are also new available options to integrate the PV cell in traditional tiles to keep the original colour (Figure 107). However, they reduce the area of PV cells and present a much higher cost. Therefore, the selected option was the presented in Figure 106 (right), considering the use of PV tiles with thin films keeping a margin in the visible areas.

FIGURE 106: SOLAR ROOFS

FIGURE 107: NEW SOLUTIONS OF SOLAR TILES

The considered areas of PV tiles in the different directions of the roof (all with an azimuth of -10º) are presented in Table 114, as well as the PV power that can be installed. Therefore, it was considered the installation of 2,102 m^2 of thin film PV panels, ensuring an installed power of 126.1 kWp.

TABLE 114: AVAILABLE AREA AND POWER

	Area m^2	Power kW
North	564	33.8
South	767	46.0
East	468	28.1
West	303	18.2
Total	**2,102**	**126.1**

Such scenario was simulated with PVSYST using the following parameters for the site and simulation (Table 115 and Table 116, respectively).

TABLE 115: SITE PARAMETERS

Geographical Site	Coimbra
Country	Portugal
Latitude	40.1°N
Longitude	8.2°W
Time	Defined as Legal Time
Time zone	UT+1
Altitude	141 m
Albedo	0.20
Meteo data	Coimbra, Synthetic Hourly data

TABLE 116: SIMULATION PARAMETERS

Collector Plane Orientation	Tilt 30° Azimuth -10°
Horizon	Free Horizon
Near Shadings	No Shadings

With these parameters, the following irradiation levels (Figure 108) and system output energy (Figure 109) over the whole year were obtained.

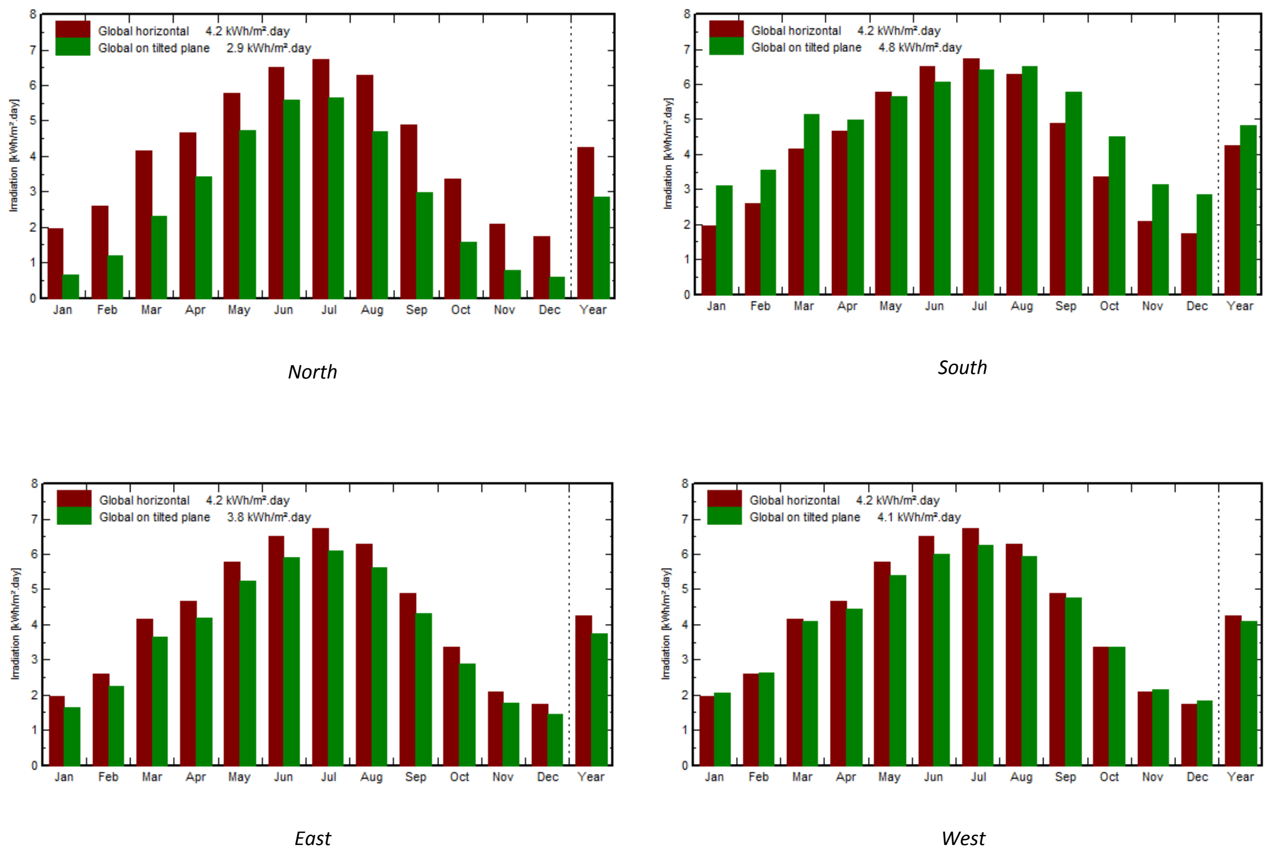
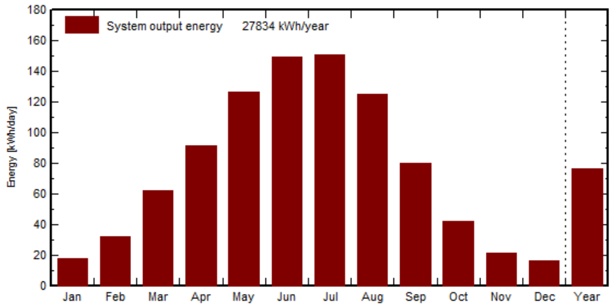
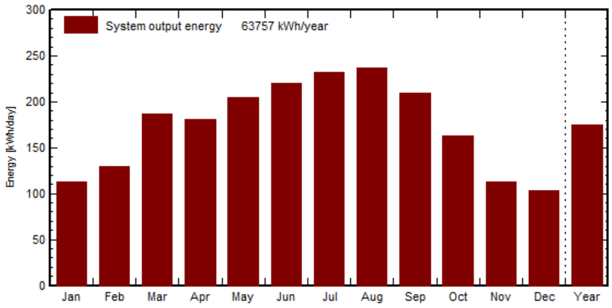


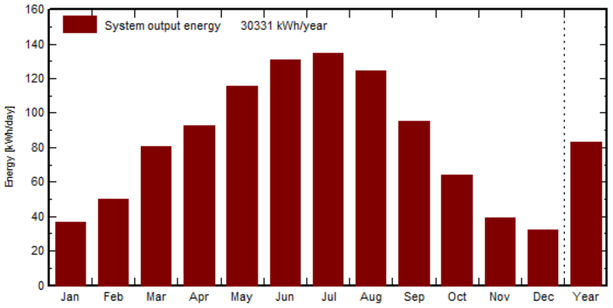
FIGURE 108: IRRADIATION LEVELS



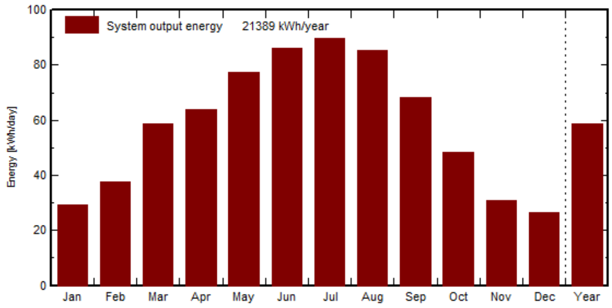
North



South



East



West

FIGURE 109: SYSTEM OUTPUT ENERGY

Table 117 presents the variation during the whole year of the irradiation and energy. As can be seen in Table 118, this scenario ensures a generation of 254.2 MWh/year, with a specific production of 1,405 kWh/kWp/year.

TABLE 117: BALANCES AND SIMULATION RESULTS

	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System out. kWh/day	System out. kWh
Jan.	7.84	7.45	195.61	6,064
Feb.	10.40	9.63	248.40	6,956
Mar.	16.64	15.19	387.88	12,024
Apr.	18.64	17.04	428.42	12,851
May	23.08	21.00	524.05	16,243
June	26.00	23.57	586.17	17,585
July	26.96	24.39	607.39	18,831
Aug.	25.16	22.76	571.03	17,703
Sep.	19.60	17.81	452.27	13,568
Oct.	13.40	12.30	316.89	9,824
Nov.	8.40	7.85	204.76	6,143
Dec.	6.96	6.74	178.01	5,519
Year	**16.96**	**15.51**	**392.66**	**143,311**

TABLE 118: MAIN SIMULATION RESULTS

Produced Energy	143.3 MWh/year
Specific prod.	1,136 kWh/kWp/year

The variation during the year of the total energy injected into grid is presented in Figure 110.

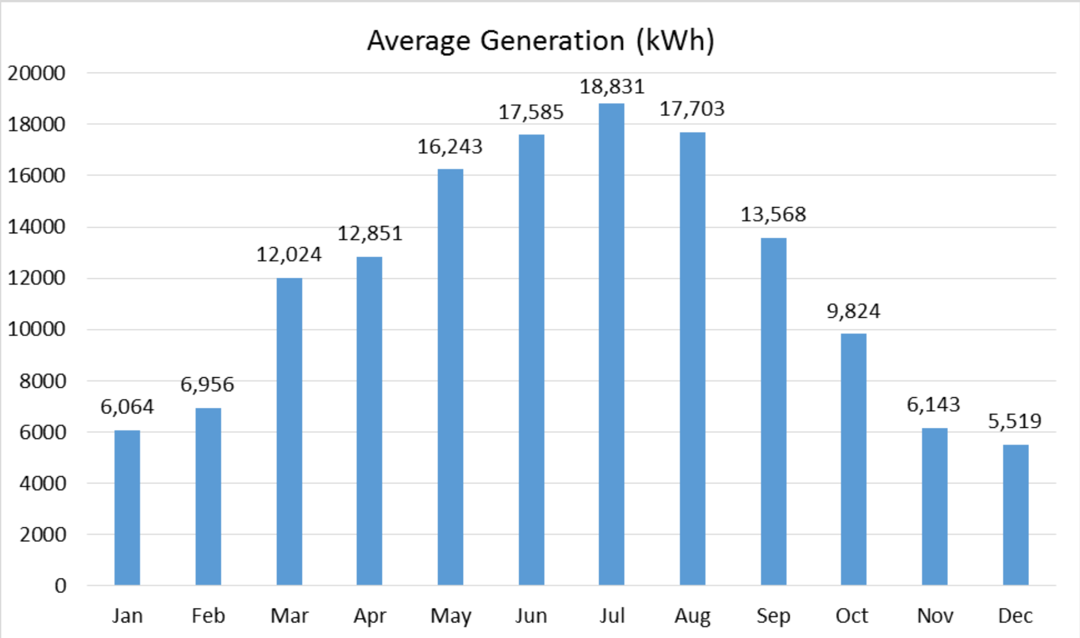


FIGURE 110: ENERGY INJECTED INTO GRID

Table 119 presents the yearly generation, as well as the percentage of consumption that can be ensured. As can be seen, it ensures about 47% of the actual energy needs. As presented in detail in section 12.2, it was considered that 10% of the yearly generation has to be inejected into the electrical grid.

TABLE 119: YEARLY GENERATION

Consumption (kWh)	305,107
Generation (kWh)	143,311
Generation (% of Cons.)	47%

11.4.2. Solar Thermal Collectors

The building does not have a regular need of hot water and therefore the installation of solar thermal collectors was not considered in the renovation plan.

11.4.3. CHP

The building does not have a constant need of heating and therefore the installation of CHP technologies was not considered in the renovation plan.

11.5. Total Impact of the Renovation Scheme

11.5.1. Energy Performance

In the assessment of the total impact the following individual scenarios were considered:

- PV – 126.1 kWp of PV tiles;
- Light1 – Replacement of all T8 lamps with electromagnetic ballast by T5 lamps with electronic; and replacement of the incandescent lamps by CFLs
- Light2 - Replacement of all lamps by LEDs;
- HVAC – Replacement of the THC and mono-split system by systems with higher COP/EER.

Additionally, it was considered the aggregation of scenarios.

Table 120 present the achievable savings, as well as the net energy consumption (difference between the energy consumption and generation) in each scenario.

TABLE 120: SAVINGS AND NET ENERGY CONSUMPTION IN SEVERAL SCENARIOS

Scenario	Savings	Net-consumption	
Baseline	0 kWh	305,107 kWh	100%
PV	143,311	161,796	53.0%
Light1	12,938	292,169	95.8%
Light2	48,916	256,191	84.0%
HVAC	57,372	247,735	81.2%
Light1+HVAC	70,310	234,797	77.0%
Light2+HVAC	106,288	198,819	65.2%
PV+Light1	156,249	148,858	48.8%
PV+Light2	185,570	119,537	39.2%
PV+Light1+HVAC	213,621	91,486	30.0%
PV+Light2+HVAC	242,942	62,165	20.4%

Table 121 present the achievable savings, as well as the net energy in each scenario, considering the additional impact of the renovation of ICT.

TABLE 121: SAVINGS AND NET ENERGY CONSUMPTION IN SEVERAL SCENARIOS (INCLUDING RENOVATION OF ICT)

Scenario	Savings	Net-consumption	
Baseline	0 kWh	305,107 kWh	100%
ICT	48,380	256,727	84.1%
PV+Light2+HVAC+ICT	262,001	43,106	14.1%
PV+Light2+HVAC+ICT	291,322	13,785	4.5%

As can be seen, the best scenario (PV+Light2+HVAC) ensures a net energy consumption of 20.4% and including the impact of the renovation of ICT the net energy consumption is reduced to 4.5%.

The selected scenario is constituted by:

- Installation of 126.1 kWp of PV tiles;
- Replacement of all lamps by LEDs;
- Replacement of the THC and mono-split systems by systems with higher COP/EER.

11.5.2. Environmental Performance

As can be seen in Table 122, with the renovation 70% of the consumed energy is ensured by renewable energy sources, therefore achieving the aim of 50-90% renewable energy sources.

TABLE 122: RENEWABLE GENERATION SHARE

	Energy Consumption kWh	Energy Generation kWh	Energy Generation %
Renovation	205,476	143,311	69.7%

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

- electricity to primary energy - 2.5 (standard value approved for Portugal);
- electricity to CO_2 emissions - 139.89 g/kWh (average emissions associated with the electricity consumed in Portugal during 2013);

As can be seen in Table 123, the renovation plan can ensure 80% savings in final energy, primary energy and CO_2 emissions, therefore achieving the aim of 75-80% of primary energy reduction.

TABLE 123: FINAL ENERGY, PRIMARY ENERGY AND CO_2 EMISSIONS SAVINGS

	Final Energy kWh	Energy Dens. kWh/m²	Primary Energy kWh	CO_2 Emissions kg CO_2 /kWh
Electricity base.	305,107	51.9	762,767.5	42,681.4
Gas base.	-	-	-	-
Total base.	305,107	51.9	762,767.5	42,681.4
Electricity renov.	62,165	10.6	155,412.5	8,696.3
Gas renov.	-	-	-	-
Total renov.	62,165	10.6	155,412.5	8,696.3
Savings	242,942	41,3	60,7355	33,985.2
Savings (%)	79.6%	79.6%	79.6%	79.6%

12. Economic Evaluation of the Proposed Renovation Scheme

12.1. Assumptions and Cost Figures

The costs of the selected renovation options were determined by consulting catalogues and installers and considering a typical reduction of costs due to the quantity.

Table 124 presents the considered costs for the following renovation options:

- Installation of 126.1 kWp of PV tiles;
- Installation of 1153 LED lamps;
- Installation of high efficiency multi and mono-split HVAC systems with a total power of 272.3 kW.

TABLE 124: COSTS OF THE SELECTED RENOVATION OPTIONS

Renovation Option	Equipment €	Installation €	Total €
PV	499,961	104,523	604,484
Lighting	19,125	1,683	20,808
HVAC	91,610	7,047	98,657
Total	**610,696**	**113,253**	**723,949**

Table 125 presents the actual tariffs of the consumed electricity in the building, disaggregated by period.

TABLE 125: ELECTRICITY TARIFFS

Period	Energy €/kWh	Grid €/kWh	Peak-Power €/kWh	Taxes €/kWh	Total €/kWh
On-Peak	0.0685	0.0489	0.1634	0.0648	0.3466
Mid-Peak	0.0678	0.0424	-	0.0256	0.1368
Normal Off-Peak	0.0654	0.0211	-	0.0201	0.1076
Super Off-Peak	0.0501	0.0199	-	0.0163	0.0873

Considering the actual distribution of the consumption between periods, the average costs was obtained using 2 scenarios (Table 126): considering just the daylight hours (to be used in the evaluation of PV generation) and considering all the periods.

TABLE 126: AVERAGE COST OF THE CONSUMED ELECTRICITYY

<table>
<tr><th>Period</th><th>Cost €/kWh</th><th>Consumption %</th><th>Day €/kWh</th><th>Total €/kWh</th></tr>
<tr><td>On-Peak</td><td>0.3466</td><td>18.6%</td><td rowspan="2">0.1910</td><td rowspan="4">0.1636</td></tr>
<tr><td>Mid-Peak</td><td>0.1368</td><td>53.4%</td></tr>
<tr><td>Normal Off-Peak</td><td>0.1076</td><td>8.5%</td><td></td></tr>
<tr><td>Super Off-Peak</td><td>0.0873</td><td>19.4%</td><td></td></tr>
</table>

12.2. RESULTS

In the evaluation of the PV generation it was considered the self-consumption of 90% of the generated energy, since the PV system only generates about 80% of the needed energy after the renovation and therefore in a working day all the generation can be consumed locally. The exceptions are the weekends, since the consumption is lower and therefore part of the energy should be injected into grid. In the economic evaluation, the self-consumption was considered to avoid the average cost of energy during the daylight hours (0.1533 €/kWh), the energy injected into the grid, with the new Portuguese regulation for self-consumption, is paid with 90% of the average cost of the electricity in the Electricity Market during the correspondent month (it was considered as 0.05 €/kWh). As can be seen in Table 127, with such conditions the renovation options ensures savings of 25352 €/year and has a simple payback period of 23.8 years.

TABLE 127: ECONOMIC PARAMETERS OF THE RENOVATION – PV GENERATION

Energy Generation	143,311 kWh
Energy - Self-Consumption	90%
Energy - Injected Into Grid	10%
Price – Self-Consumption	0.1910 €/kWh
Price - Injected Into Grid	0.05 €/kWh
Costs	604,484 €
Savings	25,352 €/year
Simple Payback	23.8 years
Lifetime	30 years
CO_2 Savings	20.05 tons/year

In the evaluation of the lighting savings it was considered the average cost of the electricity. The lifetime was assessed considering the average hours of use for the lamps and its maximum total hours of operation. As can be seen in Table 128, with such conditions the renovation options ensures savings of 8,002 €/year and has a simple payback period of 2.6 years.

TABLE 128: ECONOMIC PARAMETERS OF THE RENOVATION – LIGHTING

Energy Savings	48,916kWh
Price - Saved Energy	0,1636 €/kWh
Costs	20,808 €
Savings	8,002 €/year
Simple Payback	2.6 years
Lifetime	16 years
CO_2 Savings	6.84 tons/year

In the evaluation of the HVAC savings it was considered the average cost of the electricity. As can be seen in Table 129, with such conditions the renovation options ensures savings of 9,385 €/year and has a simple payback period of 10.5 years.

TABLE 129: ECONOMIC PARAMETERS OF THE RENOVATION – HVAC

Energy Savings	57,372 kWh
Price - Saved Energy	0,1636 €/kWh
Costs	98,657 €
Savings	9,385 €/year
Simple Payback	10.5 years
Lifetime	20 years
CO_2 Savings	8.03 tons/year

Table 130 presents the aggregation of the renovation option. As can be seen, the total of the renovation plan ensures savings of 42,739 €/year and has a simple payback period of 16.61 years.

TABLE 130: ECONOMIC PARAMETERS OF THE RENOVATION – TOTAL

Energy Savings	249,599kWh
Costs	723,949 €
Savings	42,739 €/year
Simple Payback	16.94 years
CO_2 Savings	34.92 tons/year

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