



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 GREECE FULLY DOCUMENTED WITH TECHNICAL AND ECONOMIC EVALUATION***

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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 plan, nZEB, municipalities, energy efficiency, renewable energy, economic assessment

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## ABBREVIATIONS AND ACRONYMS

[illegible]

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## 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.

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## 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 three buildings of Alimos Municipality, Greece, namely, the City Hall, the Municipal office of the Environmental Services and the Municipal Library for children.

The buildings have been constructed in the period from late '80 to early '90s with typical construction characteristics of the period.

The aim of the renovation design is to achieve nearly zero energy consumption ensuring at the same time thermal and visual comfort, as well as impeccable functional conditions for both the employees and visitors. The design, detailed in the subsequent chapters, was developed along the following requirements and constraints imposed by the Technical Department of the Municipality, (i) The building facades should not be altered and, (ii) the implementation of the renovation design should take place without any significant disruption for the employees and services provided to citizens. Full or partial evacuation of the building is not foreseen as a possibility.

An additional challenge arose from the fact that nZEB levels have not been defined in Greece yet. The country is preparing the legislation that is expected to be enforced by the end of 2015. Thus, the design team adopted the energy target set by CERTuS, namely, reduction of energy consumption for heating, cooling, lighting and hot water by at least 70% and, use of renewable energy sources to cover 50% of the remaining consumption.

The design of the three buildings was developed based on the needs and energy consumption levels identified by energy auditing and short term measurements.

The objective was to maximise as possible the neutral period of the building that is the period that comfort conditions are ensured without the need to supply energy from the grid or fossil fuels. Thus, better distribution of passive solar gains and natural night ventilation options were combined with the envelope thermal insulation, window and shading improvements. New highly efficient heating and cooling systems and efficient lighting completed the overall low energy design. To further reduce the impact of the building to the environment, photovoltaic systems in all buildings and, biomass based heating in one building, were integrated. The technical appraisal of the options was carried out by means of EnergyPlus /1/ simulation code. An economic appraisal was followed aiming to determine the most feasible scenarios. It was carried out by means of an EXCEL based tool developed by CERTuS partners ETVA VIPE and SINLOC /4/. The lifelong cost of each option was calculated using market standard prices.

The renovation design has succeeded in achieving very low nearly zero energy demand in two buildings and zero in the third one, improving simultaneously comfort conditions. However, because of the high cost of certain building envelope improvement options, alternative scenarios were investigated to allow a gradual implementation. This helped to achieve reasonable payback time around 9 to 12 years depending on the scenario, without incurring any substantial increase in the achieved nearly zero energy consumption levels.

However, the cost of the overall design is high and some of the building envelope improvements entail long payback time. For this reason the team worked out alternative scenarios dealing with fewer options that allow to plan for step by step improvements as an alternative strategy for the Municipality.



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## ACKNOWLEDGEMENT

The team would like to thank the Technical Department of Alimos and specifically Mr. Ch. Vrinios, Director of the Technical Department and Ms. S. Masouri, Civil Engineer for their technical support and cooperation to this study.

## ALIMOS GENERAL INFORMATION

Alimos is one of the oldest municipalities in Attica. Its ancient name was Dimos Alimountos and it is the birthplace of the ancient great historian Thucydides. Alimos is located in the South eastern part of Athens Metropolitan area and its total area is approximately 7.5 km<sup>2</sup>. It is a coastal city encircled by urban districts, adjacent to Athens old Airport and to the largest marina in Greece covering 150,000 m<sup>2</sup> (Figure 2). The landscape of Alimos has several height differences, such as a hill at the centre of the town (hill of Pani) and seashore of approximately 4 km in total. The main sectors of activity are tourism, industry, commerce and services linked to the yachts in the nearby Marina.

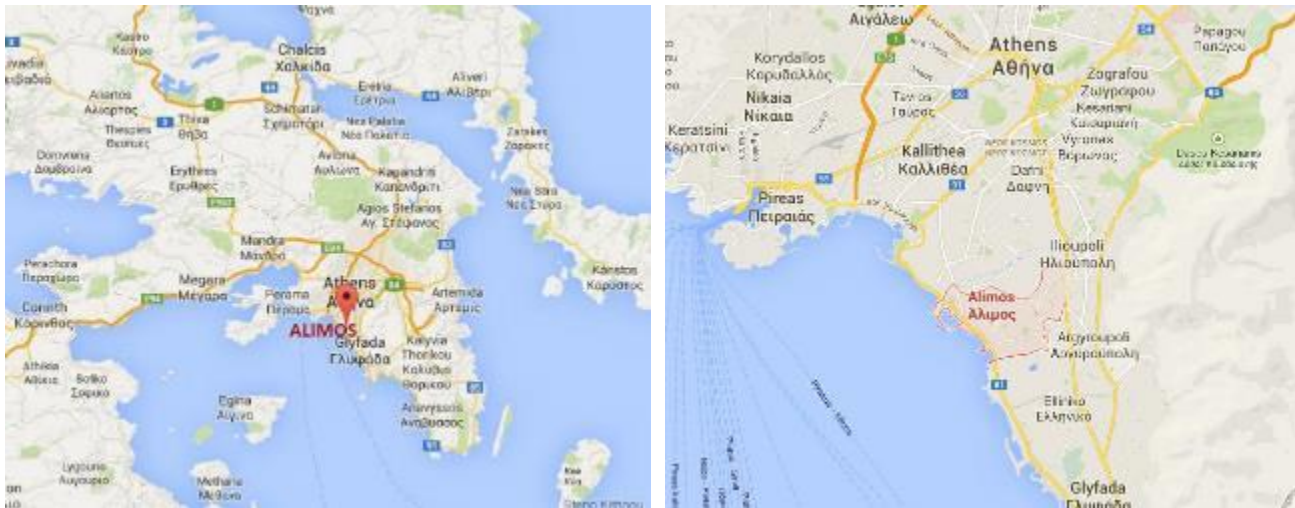


FIGURE 1: ALIMOS MAP



FIGURE 2: ALIMOS MARINA

## ALIMOS METEO DATA

The climate of Alimos is Mediterranean, with mild warm winter and warm and dry summer. The monthly meteorological data from Helliniko weather station (National Meteorological Service), which is located very close to Alimos, shows that the maximum average temperature is 28.1 °C and the average minimum is 10.3 °C in July and January respectively. The monthly peak temperature of the warmest month reaches 31.9 °C whilst the absolute maximum has been recorded at 36.4 °C. The low monthly peak temperature of the coldest month reaches 7 °C and the absolute minimum is 0.6 °C. Additionally, the annual heating degree days (HDD) are 947 (base temperature 18 °C) and the annual cooling degree hours (CDH) are 4,840 (base temperature 26 °C).

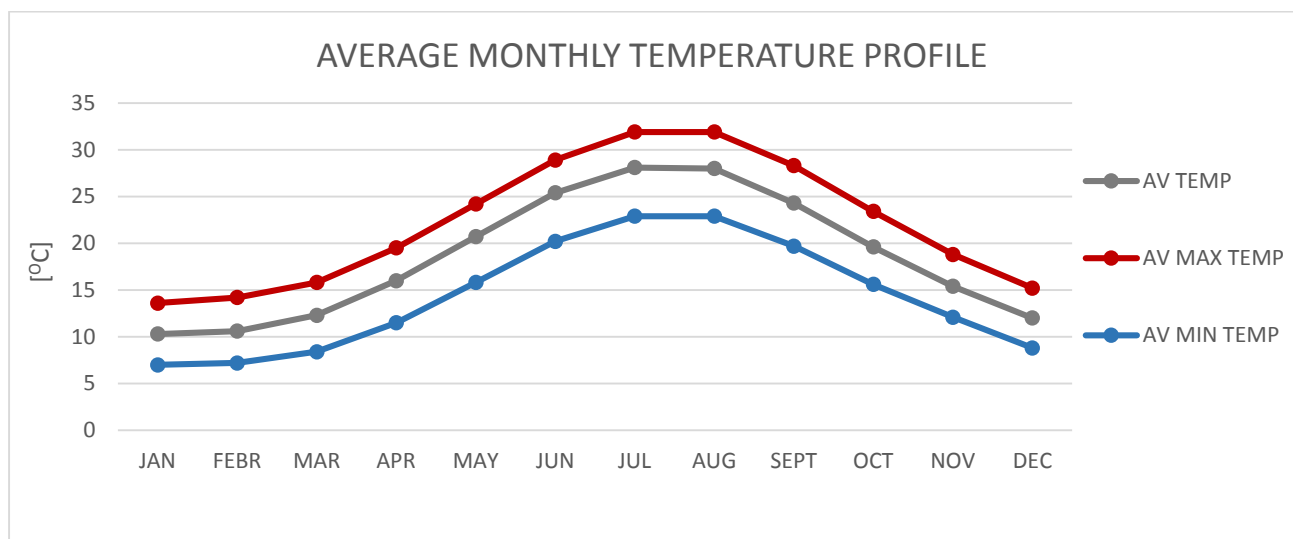


FIGURE 3: AVERAGE MONTHLY TEMPERATURE PROFILE

Alimos enjoys high solar intensity. The annual total solar radiation on a horizontal plane is 1,636.7 kWh/m<sup>2</sup> with a diffuse radiation component of 643.8 kWh/m<sup>2</sup>.

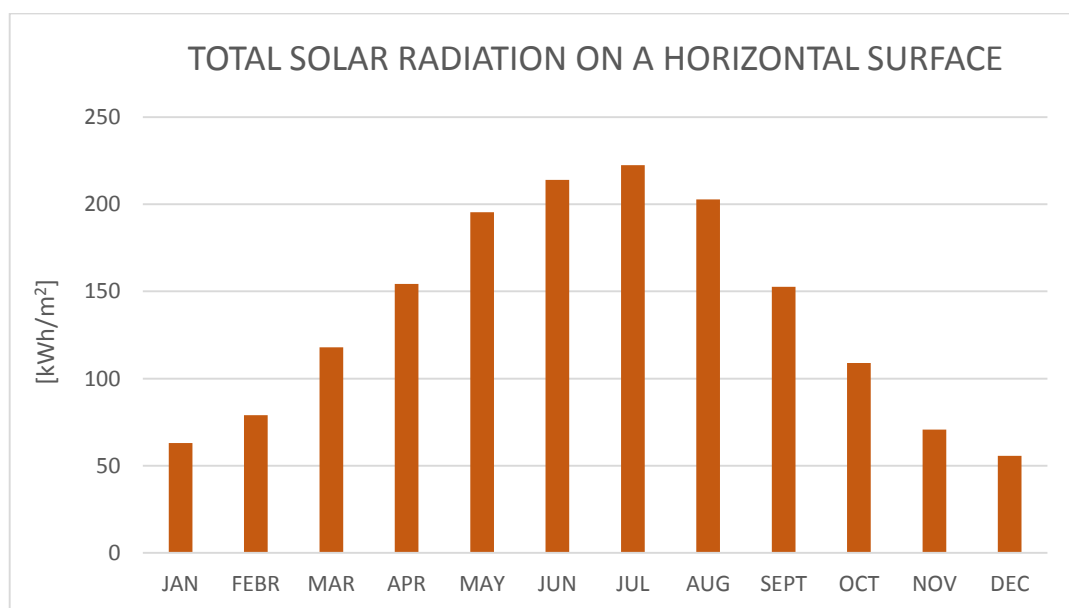


FIGURE 4: MONTHLY SOLAR RADIATION ON HORIZONTAL SURFACE

The wind comes mainly from the northwest direction year round. Secondary directions are the southwest and northwest. From all the three directions the wind is usually strong with speeds exceeding sometimes 50 km/h. However, the average maximum speed is 4 m/s (about 14.5 km/h). Figure 5 gives the wind rose for the area.

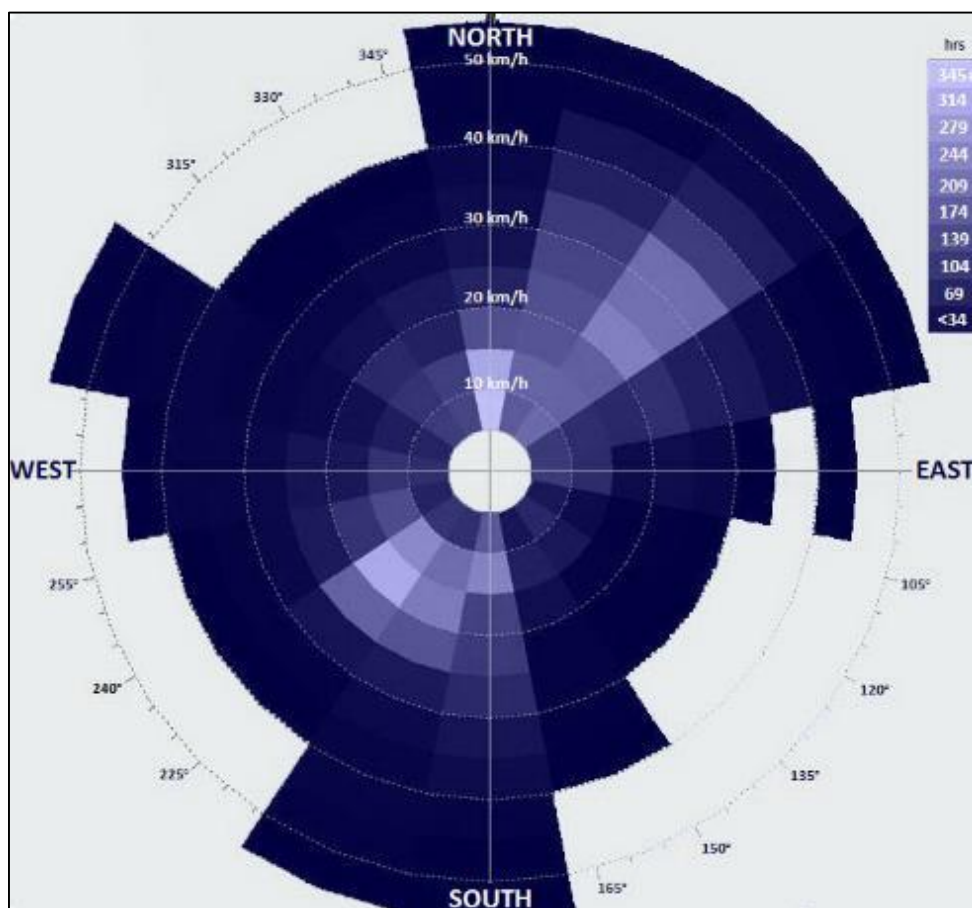


FIGURE 5: WIND FREQUENCY DATA FOR ATHENS (ECOTECT WEATHER MANAGER /2/)

The relative humidity varies from a monthly average of 46.7% in August to 70.1 in December. Detailed meteorological data are presented in ANNEX A-2.



## A. CITY HALL BUILDING

### 1. BUILDING GENERAL DESCRIPTION

#### 1.1. LOCATION

The City Hall of Alimos is located close to the sea coast and enjoys a good sea view from the upper floors. It comprises five floors and a basement. The first two levels and the basement were constructed in 1986 whilst the other 3 were added in 1996 Figure 6 depicts the front façade of the building.



FIGURE 6: ALIMOS CITY HALL – MAIN FAÇADE OF THE BUILDING

The coordinates of the building are shown in Table 1. Figure 7 & Figure 8 present the location in the map and Google Earth view.

TABLE 1: LOCATION DATA OF THE BUILDING

Address	53, Aristotelous str., 174 55 Alimos, Greece
Coordinates	37° 54' 40.49'', 23° 42' 46.06''



FIGURE 7: ALIMOS TOWN HALL (MAP)



FIGURE 8: CITY HALL LOCATION

## 1.2. SHAPE AND ORIENTATION

The shape of the initial two-floor building is elongated along the N-S axis. The 5-storey addition, at the back side, has a rectangular shape and consists of two adjacent building blocks as depicted in Figure 13. The orientation of the whole complex deviates 30° from south due west. Table 2 gives the orientation of the façades relative to north, considering north at 0°.

TABLE 2: ORIENTATION OF THE BUILDING

Orientation	Angle
NE	30°
SE	120°
SW	210°
NW	300°

The following figures presents the plan view of the ground floor, first floor and typical floor of the three upper floors as well as the cross section of the building. See ANNEX A-1 for the rest drawings of the building.

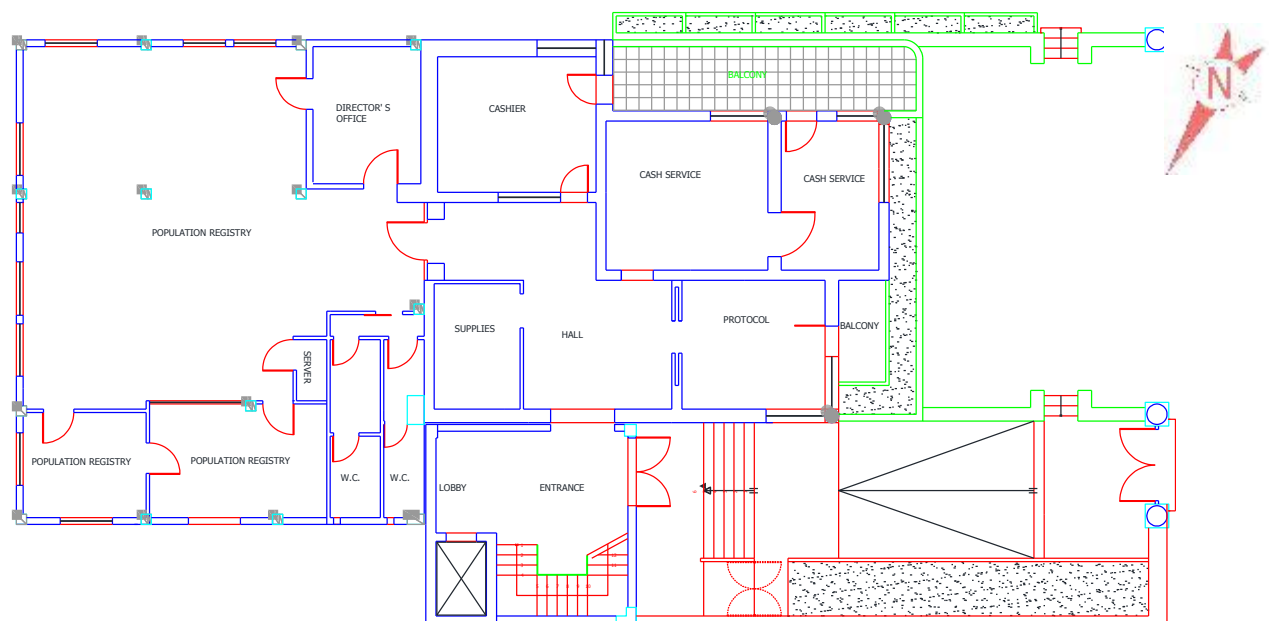
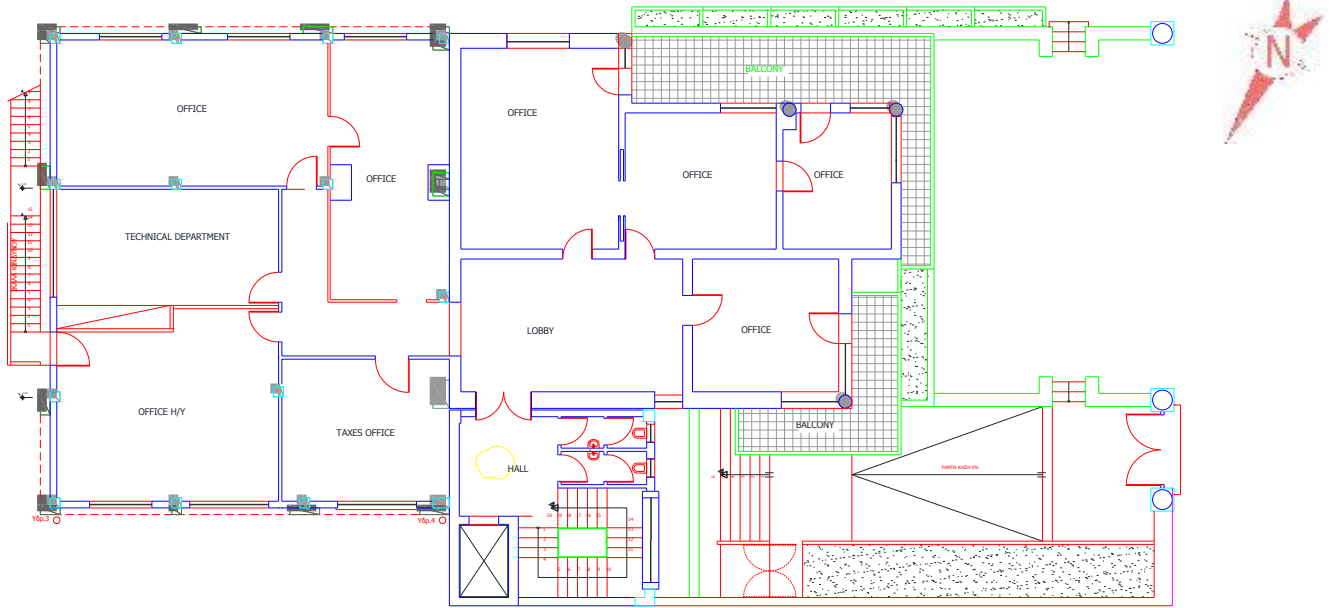
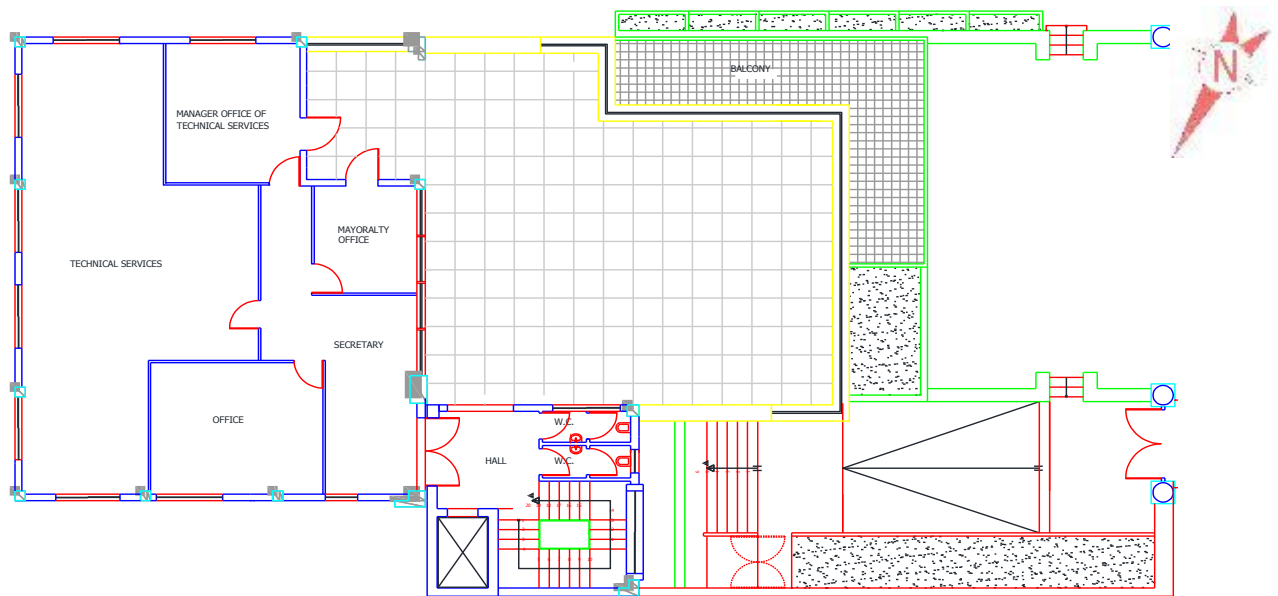


FIGURE 9: GROUND FLOOR PLAN



**FIGURE 10: FIRST FLOOR**



**FIGURE 11: TYPICAL PLAN FOR THE THREE TOP FLOORS**



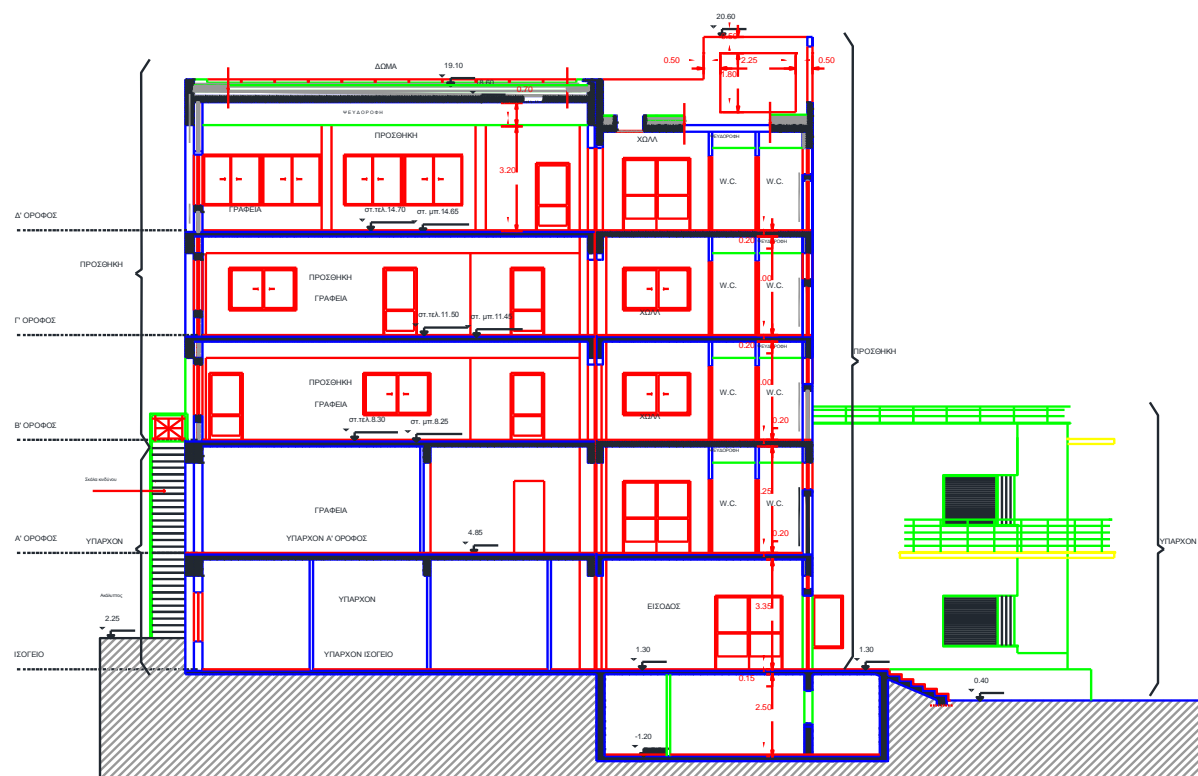


FIGURE 12: CROSS SECTION

Figure 13 shows the orientation of the building façades, the main façade is in the southwest side.

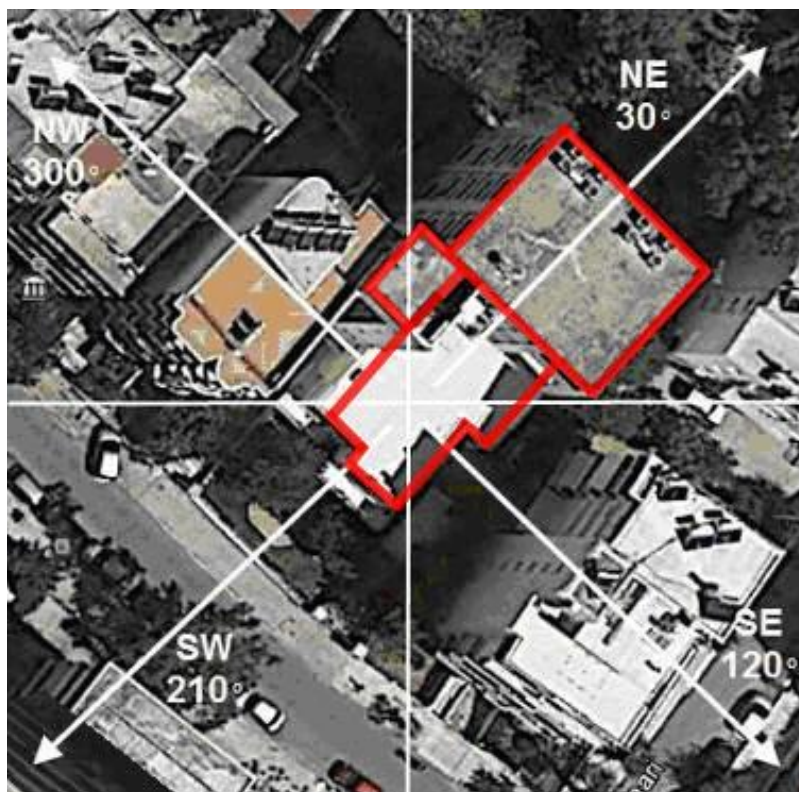


FIGURE 13: ALIMOS CITY HALL – ORIENTATION OF THE BUILDING FAÇADES

### 1.3. AREA AND VOLUME

The surface area and volume of the building are 1,302 m<sup>2</sup> and 3,612 m<sup>3</sup> respectively. The total treated area is 1,101 m<sup>2</sup> with a corresponding volume of 3,059 m<sup>3</sup>. Table 3 below gives the surface area and volume per floor and use. The untreated areas are highlighted with gray colour.

TABLE 3: ALIMOS CITY HALL - SURFACE AREA AND VOLUME

Surface areas in m <sup>2</sup> / Volume in m <sup>3</sup>			
	Offices	Communal areas, stairwells	Boiler, warehouses, canteen
<b>Basement</b>	-	16.19/42.9	28.11/74.5
<b>Ground floor</b>	305/870	37/105.0	-
<b>First floor</b>	305/839	37/102.5	-
<b>Second floor</b>	158/395	37/92.5	-
<b>Third floor</b>	158/395	37/92.5	-
<b>Fourth floor</b>	175/560	37/118.4	-
<b>Roof</b>	175	37.0	-

### 1.4. CURRENT USE

The building comprises the following areas:

- Ground floor: Houses the reception desk and areas for servicing the citizens.
- Office floors 1-4: The interior is arranged as office areas. Meeting rooms are located on the third and fourth floor. The Mayor's office is located on the fourth floor where he also meets with citizens. The office layouts for the first and second floor are arranged in such away so that staff can work together in departmental and team groupings, providing the best opportunity for efficient workflow.
- Basement: Houses the canteen and the stairwell room where the motor of the elevator is located.

Levels 1-4 and the basement are accessible by elevator or staircases.

The occupation profile of each zone is as follows:

TABLE 4: OCCUPATION PROFILE

Zone	Floor	Number of Employees	Number of Visitors/day	Hours/day of work	Hours/day of visit
1	Ground	20	50	8	1.0
2	1st	25	25	8	0.5
3	2nd	14	20	8	0.5
4	3rd	10	10	8	1.0
5	4th	8	5	10	1.0
6	Basement	1	20	8	0.2

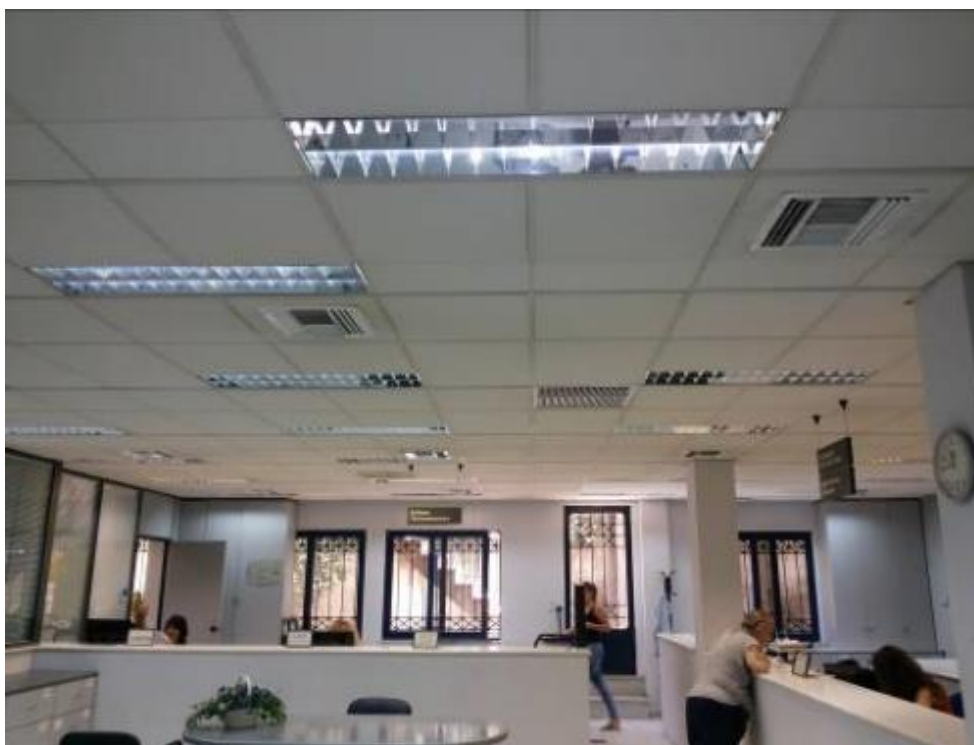


FIGURE 14: ALIMOS CITY HALL – FIRST FLOOR



FIGURE 15: ALIMOS CITY HALL – PASSAGE TO THE COURTYARD

## 2. CURRENT BUILDING CONDITIONS

### 2.1. CONSTRUCTIONAL BUILDING CHARACTERISTICS

This is a detached building. Only the northwest side of the stairwell is in contact with heated areas of the neighbouring building. Each floor is divided into two areas; the office space and the entrance hall separated with insulated walls as the latter is a non-heated area (see ANNEX A-1).

#### 2.1.1. ENVELOPE ELEMENTS

The walls consist of double brick and reinforced concrete for the load bearing structure. The walls are insulated with 4 cm of extruded polystyrene placed in between the two brick layers. The roof slab is insulated also with 4 cm extruded polystyrene while there is a mineral fibre suspended ceiling in the office space on each floor.

#### 2.1.2. WINDOWS

In all working areas, there are opening windows with double glazing in an aluminium frame. The glazing is tinted to reduce the incoming solar radiation and consequently cooling loads.

The design overall U-value of the building envelope is 0.886 W/m<sup>2</sup>K. The following Table reports the U-values of the building envelope components as they are calculated in the thermal insulation study of the building.

TABLE 5: ALIMOS CITY HALL – U-VALUES

Element	Material	U-Value (W/m <sup>2</sup> K)
Wall	Double brick with 4 cm insulation in between	0.53
Load bearing structure	Reinforced concrete	0.57
Basement	Concrete slab with marble tiles	0.93
Roof	Flat reinforced concrete with 4 cm insulation	0.45
Windows	Double glazing in aluminium frame	3.49

#### 2.1.3. AIRTIGHTNESS AND PATHOLOGIES

The building envelope does not present any problem with respect to airtightness. There is, however, a considerable loss of heating and cooling energy due to infiltration from the main entrance door that opens directly to the reception desk.

The envelope has many thermal bridges due to the type of wall construction as described earlier, and these problems have not been addressed adequately in the thermal study.

Some of the windows have presented moisture problems in –between the two glass panes. Most of them have been replaced, but there are still some problematic ones (see Figure 16).

The windows and the doors of the building do not present any problems of airtightness and the building does not present other major pathologies.

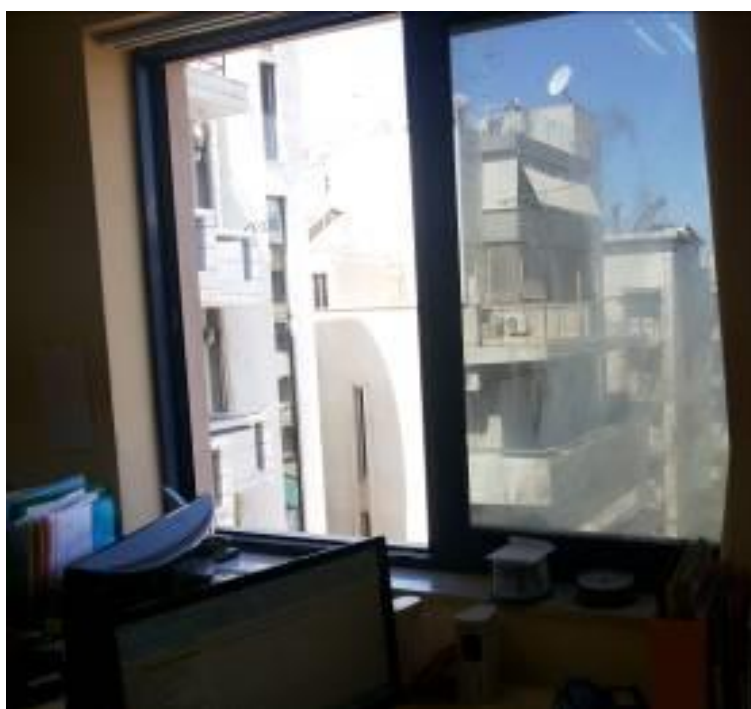


FIGURE 16: MOISTURE BETWEEN THE TWO GLASS PANES

## 2.2. ENERGY SYSTEMS

### 2.2.1. HVAC

All building areas except the entrance buffer zone on each floor are supplied with heating and cooling that is provided with electricity. There are two types of air conditioning systems used: a) small split systems b) ceiling mounted and floor standing units with inlet and outlet vents.

The total installed capacity of the A/C systems in the building is 228 kW.



FIGURE 17: A/C SYSTEM – AIR VENTS



FIGURE 18: A/C SYSTEM – INTERNAL UNIT MOUNTED ON THE WALL

Ceiling vents do not serve all areas, some offices use air conditioning split units.





FIGURE 19: SPLIT A/C SYSTEM - EXTERNAL UNIT



FIGURE 20: FLOOR STANDING UNIT



FIGURE 21: A/C SYSTEM - EXTERNAL UNITS

TABLE 6: INSTALLED CAPACITY OF THE BUILDING A/C SYSTEMS.

System	Power (kW)	Units	Total Power (kW)
Fuji Electric - Split unit (24.000 Btu/h)	7.03	1	7.03
York - Floor standing unit (60.000 Btu/h)	17.58	2	35.16
York – Ceiling mounted type (60.000 Btu/h)	17.58	1	17.58
Carrier - Split unit (12.000 Btu/h)	3.52	1	3.52
Daikin Inverter - Split unit (9.000 Btu/h)	2.64	1	2.64
Fujitsu General – Floor Split unit (24.000 Btu/h)	7.03	1	7.03
	Total:		65.93
Trane - Floor standing unit (50.000 Btu/h)	14.65	1	14.65
Trane – Ceiling mounted type (50.000 Btu/h)	14.65	1	14.65
Fuji Electric Inverter - Split unit (12.000 Btu/h)	3.52	1	3.52
Panasonic - Split unit (12.000 Btu/h)	3.52	1	3.52
Fujitsu General - Split unit (12.000 Btu/h)	3.52	1	3.52
Fujitsu Inverter- Split unit (12.000 Btu/h)	3.52	1	3.52
Carrier - Split unit (12.000 Btu/h)	3.52	2	7.04
	Total:		50.42
Carrier Inverter - Split unit (12.000 Btu/h)	3.52	1	3.52
Fujitsu Inverter - Split unit (24.000 Btu/h)	7.03	1	7.03
Fujitsu General - Split unit (18.000 Btu/h)	5.28	1	5.28
LG - Split unit (12.000 Btu/h)	3.52	1	3.52
Carrier Inverter - Split unit (18.000 Btu/h)	5.28	1	5.28
	Total:		24.63
York - Floor standing unit (60.000 Btu/h)	17.58	2	35.16
Fujitsu General - Split unit (9.000 Btu/h)	2.64	1	2.64
	Total:		37.80
York - Floor standing unit (60.000 Btu/h)	17.58	2	35.16
Fuji Electric - Split unit (24.000 Btu/h)	7.03	1	7.03
Ventilation system	0.15	1	0.15

It should be noted that the reported EER and COP are nominal values provided by the manufacturers. However, because of the age and the inadequate maintenance of the devices the current performance of the A/C equipment is considered to be 1.7 for heating and 1.5 for cooling, according to the regulation for energy efficiency, KENAK<sup>1</sup>.

Due to the configuration of the interior space which is divided into small rooms, thermal comfort problems are observed. Specifically in some offices on the third and fourth floor the employees complained that often felt very cold in the summer when the air conditioners were turned on and, in some offices on the second

<sup>1</sup> Law 3661/2008 "Measures to reduce energy consumption in buildings and other provisions" was amended. The new regulation for the Energy Performance of Buildings (KENAK) approved by the Δ6/B/οικ.5825/30-03-2010 Joint Decision of the Ministers of Finance and Environment, Energy & Climate Change (Official Gazette B' 407).

floor the heating in winter was not sufficient. At the northeast and northwest offices on the second floor, incorrectly installed units were distributing the air straight to the users creating annoying thermal conditions. Also in some offices, in the second and fourth floor, the A/C floor standing unit produced so much noise that the users were not able to work.

### 2.2.2. LIGHTING

Lighting is mainly supplied by fluorescent T8 lamps with magnetic ballast. The total installed capacity of lighting in the building is 17,885 W. All types of lighting systems that the building uses are presented below:

Type A: Ceiling lamp, square, 60 cm x 60 cm, with 4 lamps T8 fluorescent 18 W (4x18 W), magnetic ballast, condenser and compensation with reflector and louver. This lighting system is the most common in the building, located mainly in offices and at certain areas in the hallways.

Type B: Ceiling lamp, with 2 lamps T8 fluorescent of 36 W (2x36 W), length 120 cm, body with reflector and louver.

Type C: Round lamp 35 W, located in WC.

Type D: Oval wall lamp 60 W, located in every floor of the stairwell.

Type E: Circular fluorescent roof lamps 32 W, are located in the entrance hall of each floor.



FIGURE 22: TYPE A - FLUORESCENT CEILING LAMP 4X18 W

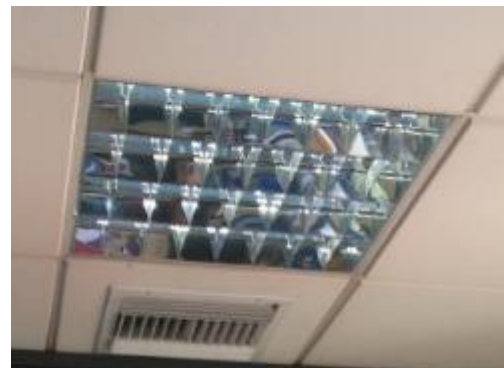


FIGURE 23: TYPE B - FLUORESCENT CEILING LAMP 2X36 W

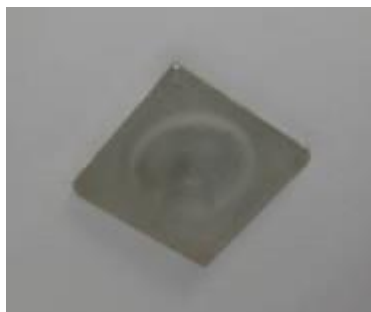


FIGURE 24: TYPE D - OVAL LAMP 60 W



FIGURE 25: TYPE C - ROUND LAMP 35 W



### 2.2.3. OTHER

Other electrical loads are generated from the buildings ICT equipment such as PC units, servers, printers, photocopiers, and, other electrical devices (e.g. elevators, water cooler, coffee machine and refrigerator). Their total power is 63,210 W.

TABLE 7: ELECTRICAL LOADS PER USE

Devices	Total Power (W)
PC	35,500
Printer	1,320
Copy machine	6,550
Server	1,900
Water cooler	500
Coffee machine	600
Refrigerator	840
Elevator motor	16,000
<b>Building Total:</b>	<b>63,210</b>

## 2.3. ENERGY CONSUMPTION AND ENERGY GENERATION

### 2.3.1. ELECTRICITY CONSUMPTION

All energy needs of the building are covered by electricity. The building receives electricity in Low Voltage. Based on the Utility invoices of the last 3 years the annual average consumption of the building is 156,613 kWh and the average annual total specific consumption is 121 kWh/m<sup>2</sup>.

The monthly electricity consumption for the same 3-year period (25/01/2011 - 22/01/2014) is depicted in the following diagram.

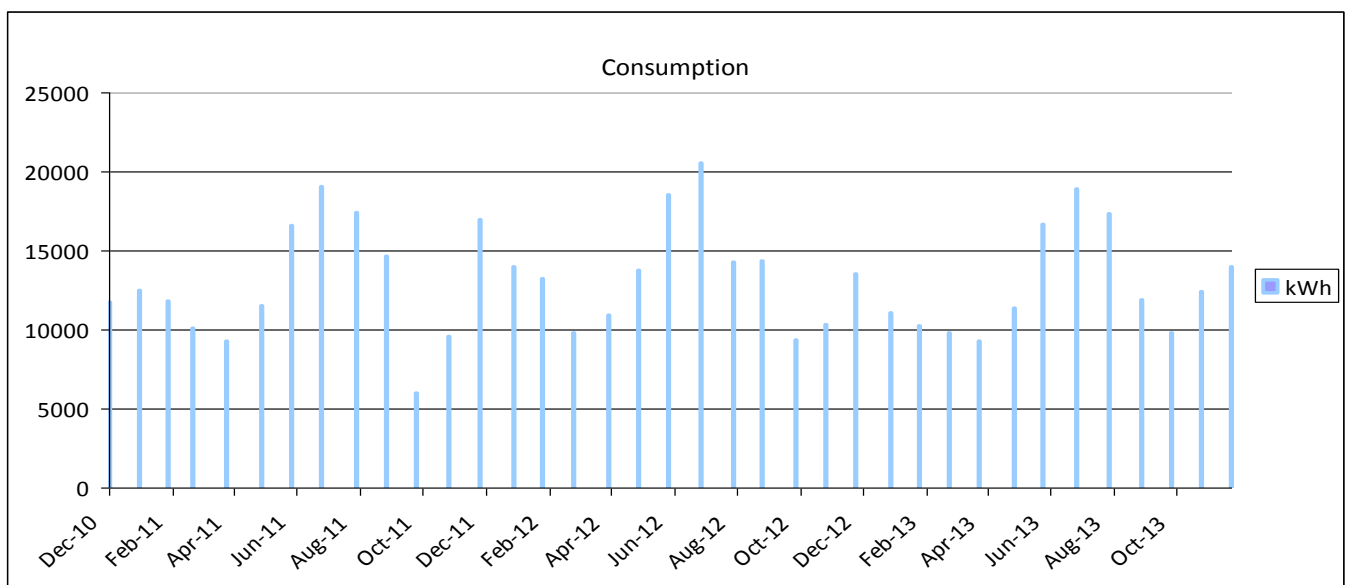


FIGURE 26: MONTHLY ELECTRICITY CONSUMPTION DURING THE PERIOD 2011-2013

As can be noticed from the above figure, the higher consumption occurs during summertime and is due to cooling. This is in agreement with the building use and operation profile, as well as the warm climate of the area. More specifically, cooling peak is much higher due to the fact that during summer, the demand occurs during the warmer period of the day when the solar intensity and outdoor temperatures are high. Contrarily, during the heating period the highest demand occurs at night when the building is not in operation. In spring and autumn, the energy consumption reaches its lowest point as there is no need for heating or cooling.

The electricity consumption was disaggregated between uses by means of EnergyPlus building simulation code. The building model and its equipment and occupant profile are detailed in chapter 3.6.1, and ANNEXES A-3, A-4 and A-5. As shown in the next Figure the major consumption is for cooling, followed by lighting and other equipment.

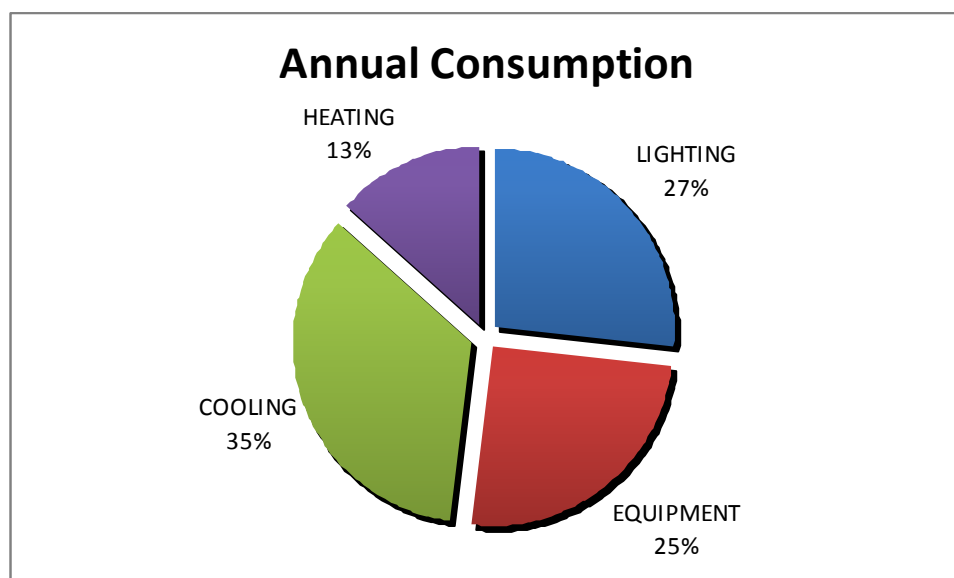


FIGURE 27: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES

Measurements were carried out in order to check the three-phase distribution and the power factor ( $\cos\phi$ ) of the building. The three-phase instant consumption of the building was measured for each floor by using a clamp-on power meter (HIOKI). These measurements show the 3-Phases are not balanced and this can cause electrical current distribution problems or overheated electrical fuses. Also the power factor  $\cos\phi$ , was found to vary from 0.612 to 0.924 a range of values below the standard value of 0.95 the lowest permitted value for public buildings. The replacement of the current T8 fluorescent lamps with LED will contribute to the improvement of the power factor.

#### 2.3.2. GAS/OIL CONSUMPTION

The building does not use gas or oil.

#### 2.3.3. RENEWABLE ENERGY SOURCES

The building does not use any renewable energy sources.

#### 2.3.4. OTHER GENERATION

The building does not use any other source of generation.

### 2.3.5. FINAL ENERGY CONSUMPTION AND CO<sub>2</sub> EMISSIONS

Summarising the data of the monthly electrical consumption from the Utility invoices we have the following consumptions per year:

TABLE 8: ANNUAL ELECTRICITY CONSUMPTION DURING THE PERIOD 2011-2013

Year	Total Consumption (kWh)
2011	155,080
2012	162,360
2013	152,400
Average	156,613

The average annual total specific consumption of the building is 121 kWh/m<sup>2</sup>.

Table 9 presents the annual electrical consumption of the building converted to primary energy and the corresponding CO<sub>2</sub> emissions. The values were calculated using the following conversion factors in accordance with the Greek regulation of the energy performance of buildings, KENAK:

- electricity to primary energy – 2.9
- electricity to CO<sub>2</sub> emissions – 0.989 kg/kWh

TABLE 9: YEARLY PRIMARY ENERGY AND CO<sub>2</sub> EMISSIONS

Year	Final Energy kWh	Primary Energy kWh	CO <sub>2</sub> Emissions kg CO <sub>2</sub> /kWh
2011	155,080	449,732	153,374
2012	162,360	470,844	160,574
2013	152,400	441,960	150,724
Average	156,613	454,178	154,890

## 3. RENOVATION SCHEME

### 3.1. AIM OF THE RENOVATION PLAN

The renovation design was developed along the following requirements and constraints imposed by the Technical Department of the Municipality, (i) the building facades should not be altered and, (ii) the implementation of the renovation design should take place without any significant disruption for the employees and services provided to citizens. Full or partial evacuation of the building is not foreseen as a possibility.

Moreover, due to the tight economic conditions the Municipality expects that the renovation works will be financed by private funds (e.g. via an ESCO contract or similar). The Municipality's contribution in the investment initial capital will be limited. This fact restricts the choice of the renovation options to those that have become mainstream as opposed to innovative energy systems that are usually more energy efficient and environment friendly but, may entail higher risks, making financing more difficult.

In addition to the constraints above, there are technical difficulties, related to the integration of renewable energy systems in the building, resulting from the densely built urban setting that limits both solar and wind potential, and, space availability to accommodate RES systems in general.

Therefore, the renovation design was developed within these constraints and difficulties without compromising the energy target or the indoor air quality, or full functionality. Moreover, it should facilitate full monitoring and evaluation of the operational conditions as well as the energy consumption and electricity generation after renovation.

To achieve this objective, a methodology was used based on an iterative process that optimises the design considering energy efficiency, operability, technological risk and cost effectiveness. The selection of renovation options was made based on the market investigation for both mainstream and innovative systems. The technical appraisal regarding the energy efficiency improvement of the selected options was made by means of EnergyPlus simulation code (see ch. 3.6). Finally, the economic appraisal was performed based on the tool produced by ETVA, partner of the CERTUS consortium /4/.

The resulting renovation design is comprehensive and tackles both the efficiency of the building envelope and the services. It utilises natural heat sources and sinks to reduce energy demand by means of passive options such as (i) solar gains during winter and shading during summer and, (ii) the use of natural ventilation in summer.

The holistic approach of the building renovation includes extra insulation to the entire envelope, new low-e and thermal break windows and external louvers to selected openings. Natural ventilation is improved to avoid the overheating of the building and to achieve the appropriate internal air quality. Other strategies to reduce even more the energy demand are the night ventilation, the solar gains circulation in winter and the use of available daylight. After minimizing the energy demand, very efficient systems are foreseen to cover the needs of buildings for heating, cooling, mechanical ventilation and lighting. Finally, renewable energy systems are added to supply “green electricity”. A BEMS is foreseen to monitor the operation of the building and systems and control the proper operation of the heating, cooling and lighting equipment.

## 3.2. ENERGY DEMAND REDUCTION

### 3.2.1. OPAQUE ENVELOPE

The building envelope is in good condition but has significant thermal bridges that increase the current overall U-value of the opaque part, by about 30%. This is due to the type of wall construction (insulation in – between the two brick layers) that makes the avoidance of thermal bridges difficult. Moreover, the current U-values of the external walls and roof are higher than those required by the new building regulation for energy efficiency, KENAK.

Therefore, the addition of external insulation was investigated as a means to improve the current conditions. Its impact on the year-round energy performance of the building was modelled by means of the simulation code EnergyPlus (see Ch. 3.6). For modelling purposes, an insulating material with 0.032 W/mK thermal conductivity was considered.

Three different values of thickness, namely, 5 cm, 7 cm, and 10 cm were successively studied. As can be seen in Figure 28, by applying 5 cm of external insulation there is an annual decrease in heating of 4,517 kWh. Any further increase of the insulation thickness does not significantly affect the energy consumption.

Additionally, the installation of 10 cm would require not only an extra budget but extra structural works in order to be adequately supported.

Thus, the most suitable option is the addition of 5 cm external insulation of 0.032 W/mK. Any other equivalent combination is equally suitable.

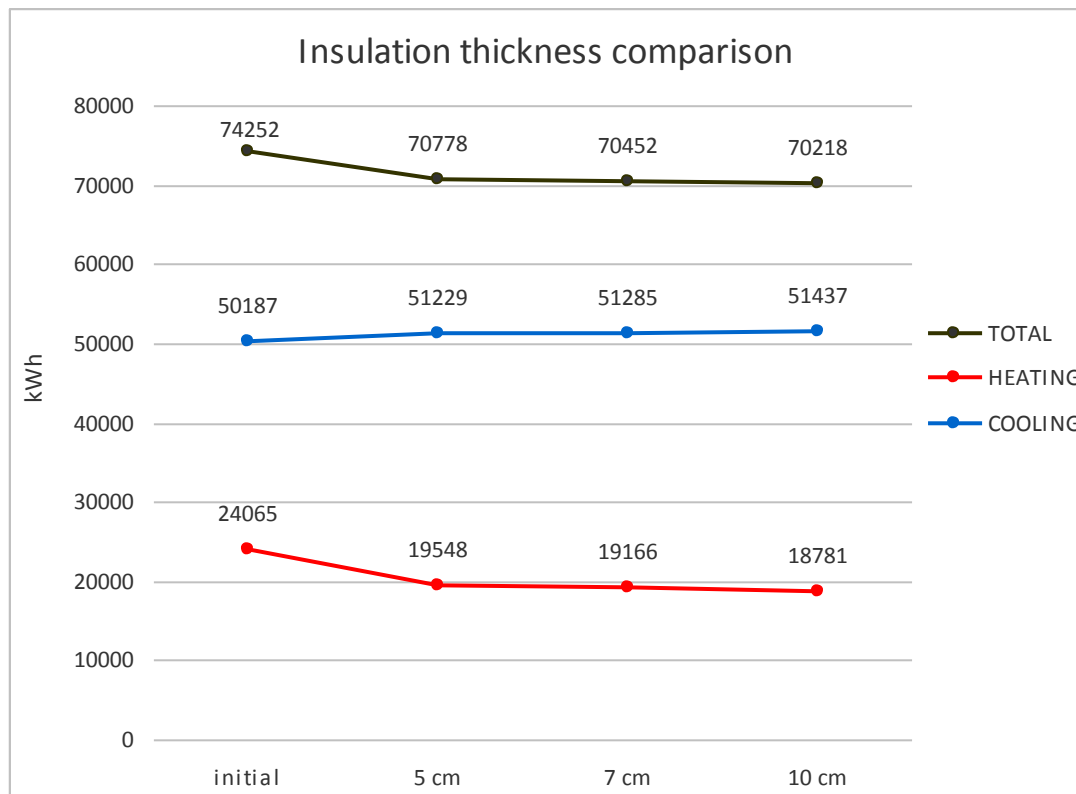


FIGURE 28: ENERGY PERFORMANCE ACCORDING TO DIFFERENT WIDTH OF INSULATION

Further requirements for the selection of the external insulation system are:

- provide full waterproofing
- good vapour diffusivity
- fulfil all the requirements of the current regulation

The insulation materials EPS and natural mineral wool that were examined satisfies all technical requirements.

The application of the insulation has to follow very strict specifications in order to avoid potential failures of the system. Thermal bridging is one of the biggest issues which have to be tackled. Also, special attention must be given to the insulation and sealing of the openings. Finally, it is very important to have very good and tight application at ground level and generally in all areas where the insulating material is in contact with other elements of the building.

The addition of the investigated external insulation reduces the U-value of the walls from 0.526 W/m<sup>2</sup>K to 0.272 W/m<sup>2</sup>K and the U-value of the roof from 0.451 W/m<sup>2</sup>K to 0.250 W/m<sup>2</sup>K.

The performance of the building envelope was further improved with the addition of a thermal buffer zone installed in front of the main entrance to reduce infiltration by the frequent opening of the door.

The impact of these two measures on the building load is shown in the following Table.

TABLE 10: ANNUAL CONSUMPTION BEFORE AND AFTER ADD INSULATION

	Before	Retrofit	After Retrofit	
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	24,065	50,184	19,548	51,229
<b>Savings (kWh)</b>	-	-	↓ 4,517	↑ 1,045
<b>Savings (%)</b>	-	-	↓ 19%	↑ 2%

### 3.2.2. OPENINGS

The existing glazing and frames with total U-value of 3.49 W/m<sup>2</sup>K will be replaced with low-e glazing and thermal break frame. After doing an investigation on different U-values (see Figure 29), it was decided that the optimum choice should have the following thermal properties: U<sub>frame</sub> 2.50 W/m<sup>2</sup>K, U<sub>glazing</sub> 1.10 W/m<sup>2</sup>K and the resulting window mean U-value 1.80 W/m<sup>2</sup>K. A low-e coating is foreseen on the internal side of the external glass pane to reduce incoming heat. The glazing has 42% Solar Factor and 66% Light Transmission.

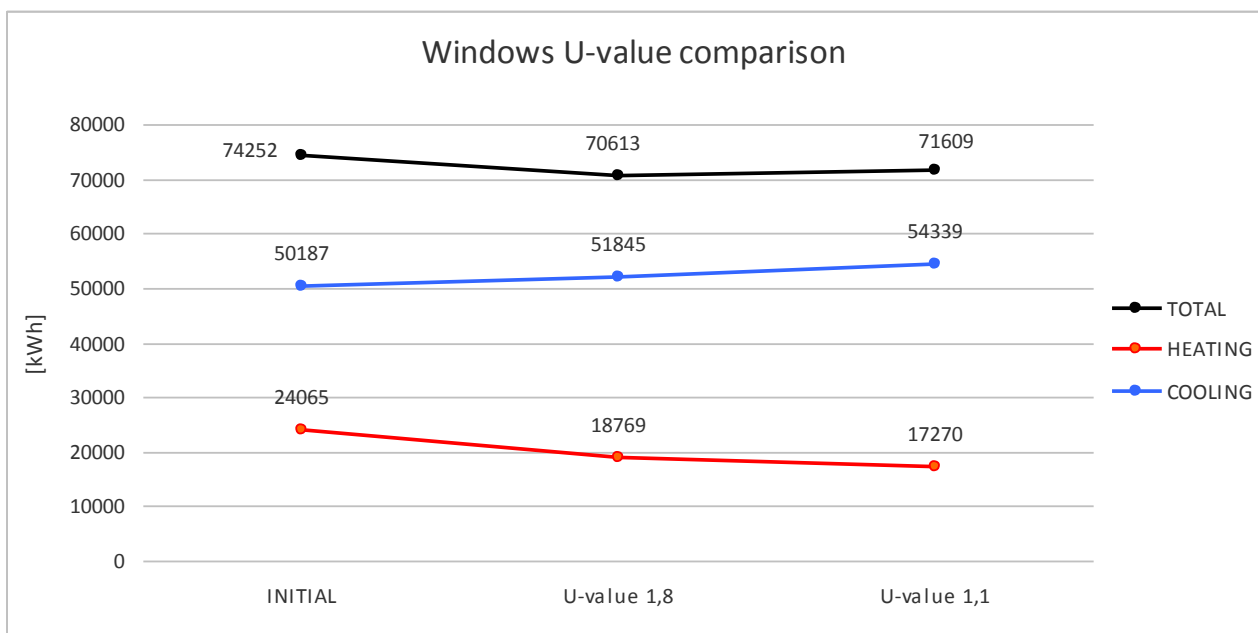


FIGURE 29: ENERGY PERFORMANCE ACCORDING TO DIFFERENT U-VALUE OF WINDOWS

As the previous figure shows the windows with lower U-value (e.g. 1.1 W/m<sup>2</sup>K) are not only more expensive but they increase the total energy consumption too. This happens because the windows with very low U-

value delay the transmission of heat, generated from the high internal gains, resulting in an increase of energy demand for cooling.

In the following Table, the impact of the windows replacement on building's energy consumption is shown.

TABLE 11: ANNUAL CONSUMPTION BEFORE AND AFTER REPLACE THE WINDOWS

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	24,065	50,184	18,769	51,845
<b>Savings (kWh)</b>	-	-	↓ 5,296	↑ 1,661
<b>Savings (%)</b>	-	-	↓ 22%	↑ 3%

It is noted that the cooling demand has increased but the overall year round energy consumption is reduced, though by a small percentage (5%).

### 3.2.3. SHADING

To enhance the thermal performance of the transparent envelope and reduce the cooling demand during summer, shading devices will be installed. The shading requirements of the openings were investigated by means of EnergyPlus. The building is shaded partially by neighbouring buildings. A protruding part of the envelope casts an additional shadow on openings of the south façade. Results of the shading analysis are included in ANNEX A-6. From the analysis it is concluded that shading is needed on the east, south and west façade on all floors above the 1<sup>st</sup> floor whilst on the 1<sup>st</sup> floor only on the south facade.

External retractable louvers are selected as shading devices for all the facades except the north one. The louvers are sized according to the orientation of the openings so they will provide full shading during summer. They will be fully retractable to allow solar radiation penetration during winter and contribute to the reduction of heating energy demand.

On the north façade, shading will be provided by means of internal louvers. This is because the north facing windows receive insolation in the very early morning and evening for a very short period. At this time, the penetration of solar radiation is very limited as it is incident on the glazing with a wide angle and so the greatest part is reflected back. Moreover, the building is not occupied in these hours. Therefore, the small amount of solar heat from the north windows can be reduced with internal louvers and then be removed with night-time ventilation. This solution is by far more cost effective.

The area of openings that will be shaded is 145 m<sup>2</sup> out of the 286 m<sup>2</sup> which is the total area of the building openings.

The above shading options result in a substantial reduction in cooling demand as reported in the following Table 12.

An alternative option is the use of special glazing such as prismatic glazing that regulates reflection or transmission of the incident solar radiation according to the angle of incidence. The glazing is selected to cut off the radiation when coming from high summer angles and allow transmission from low winter angles. The

advantage of this option is the elimination of louvers which need extra installation works and scaffolding. Also, it contributes to making the building lean and to reducing operation and maintenance cost. The disadvantage is the glazing is not transparent and so there is no view out. Nevertheless, this type of glazing can be integrated on the east and west façade in combination with transparent glazing to allow the view out.

The impact of shading on energy consumption is shown in the following Table.

TABLE 12: ANNUAL CONSUMPTION BEFORE AND AFTER INSTALL LOUVERS

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	24,065	50,184	24,065	39,144
<b>Savings (kWh)</b>	-	-	0	↓ 11,040
<b>Savings (%)</b>	-	-	0%	↓ 22%

### 3.2.4. NATURAL/NIGHT VENTILATION

In order to reduce further the energy demand for cooling natural/night-time ventilation is foreseen. This strategy will help to avoid the overheating of the building and to maintain the desired indoor conditions and indoor air quality.

Air vents equipped with dampers will be installed on the north and south façade of the building so as to achieve cross ventilation on each floor. The study concludes that on each floor, two air inlet openings with dampers have to be integrated into the lower zone of the north façade and two outlet openings in the upper zone of the south façade.

This system will operate during the night in summer (night ventilation) in order to cool the internal space by blowing fresh air inside, at a rate of 15 ACH. The inlet openings are equipped with small fans to assist air inflow in case natural ventilation does not suffice. Also, this system will operate during the day to offer the required rate of natural ventilation in periods when the outside air is cooler.

The ventilation openings will be connected with sensors for the external temperature and will operate only when the external temperature is lower than the internal. The use of these sensors ensures that the maximum saving in energy consumption for cooling will be achieved. The dampers will be insulated and airtight so to avoid any increase of heating in winter.

TABLE 13: ANNUAL CONSUMPTION BEFORE AND AFTER ADD NIGHT VENTILATION

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	24,065	50,184	24,065	39,645
<b>Savings (kWh)</b>	-	-	0	↓ 10,539
<b>Savings (%)</b>	-	-	0%	↓ 21%



### 3.2.5. PASSIVE SOLAR SYSTEM

Passive systems are also integrated with the renovation plan. The big amount of solar gains which are concentrated on the south part of the building cause overheating to the adjacent offices even during the winter. In order to avoid this problem, appropriate openings will be integrated into the internal walls which separate the south and north spaces on the second and third floor. This intervention will allow the circulation of the solar gains which received through the curtain wall on the south façade of these two floors. This fact has as a result the reduction of heating demand for the north spaces and the offer of better indoor conditions for the south spaces with no extra energy consumption.

TABLE 14: ANNUAL CONSUMPTION BEFORE AND AFTER SOLAR GAINS CIRCULATION

	Before	Retrofit	After	Retrofit
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	24,065	50,184	23,824	50,184
<b>Savings (kWh)</b>	-	-	↓ 241	0
<b>Savings (%)</b>	-	-	↓ 1%	0%

## 3.3. ENERGY SYSTEMS

### 3.3.1. LIGHTING SYSTEM

As previously presented the actual lighting system consists mainly of fluorescent T8 linear 18 watt and 36 watt lamps with magnetic ballast. In total there are 764 fluorescent T8 lamps and 43 lamps of different types such as circular fluorescent lamps, round and oval compact fluorescent lamps.

All lamps of the building will be replaced with new LED lamps. Two scenarios were investigated. The first one is to replace each lamp individually by keeping the already existing ceiling panels. The second scenario is to replace the whole panel with a new ceiling LED light panel. The latter will give 10% more lumens per panel and flexibility in order to adjust to the frequent changes on the interior spaces of the building.

IN FIRST SCENARIO, 807 LAMPS HAVE TO BE REPLACED. TABLE 15 PRESENTS THE ALREADY EXISTING LAMPS AND

Table 16 shows the total power to be installed. The new installed total power is 9,350 W which is 51% of the initial power.

TABLE 15: TYPES AND QUANTITIES OF EXISTING LAMPS

Lamp Type	Quantity n	Lamp W	Total W
<b>Fluorescent Linear T8 60cm</b>	640	18	11,520
<b>Fluorescent Linear T8 120cm</b>	140	36	5,040
<b>Compact Fluorescent round lamp</b>	23	35	805
<b>Circular fluorescent roof lamp</b>	14	32	448
<b>Oval wall lamp</b>	6	60	360
		<b>Total:</b>	<b>18,173</b>

TABLE 16: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN 1<sup>ST</sup> SCENARIO

Lamp Type	Quantity n	Lamp W	Total Power W
LED Tube Glass T8 60cm	640	10	6,400
LED Tube Glass T8 120cm	140	18	2,520
LED E14	37	10	370
LED E27	6	10	60
		<b>Total:</b>	<b>9,350</b>

In the second scenario, 226 panels have to be replaced with new ceiling LED light panels and 43 lamps will be replaced with new Led lamps. Table 17 presents the lamps to be installed and as can be noticed the total power is 12,860 W which is 70% of the initial one.

TABLE 17: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN 2<sup>ND</sup> SCENARIO

Lamp Type	Quantity n	Lamp W	Total Power W
LED Ceiling Light Panel	226	55	12,430
LED compact E14	37	10	370
LED compact E27	6	10	60
		<b>Total:</b>	<b>12,860</b>

Additionally, the wiring of fixtures will be replaced to allow for better zoning of the room lighting. Also, daylight sensors will be installed on the luminaires located close to the windows of the 3 upper floors so that artificial lighting can be turned off automatically when the desired lighting levels are reached. In total sixteen (16) daylighting sensors will be installed. According to EnergyPlus simulation, this will give an additional reduction of 12.5% of the total consumption for lighting. An additional benefit with the replacement of the T8 lamps with LED is the improvement of the power factor because the operation of the latter does not require any magnetic ballast.

Table 18 presents the yearly consumption for lighting in the two scenarios and the percentage of achievable savings including the savings entailed by the use of LUX sensors. As can be seen, the savings are 55% and 38% with the 1<sup>st</sup> and 2<sup>nd</sup> scenario respectively.

TABLE 18: YEARLY CONSUMPTION WITH LIGHTING IN THE TWO DIFFERENT SCENARIOS

	Actual	Scenario 1	Scenario 2
Consumption (kWh)	37,713	19,233	26,400
Consumption + lux sensors (kWh)		16,828	23,100
Savings (kWh)	-	20,885	14,613
Savings (%)	-	55%	38%

After comparing the two scenarios the first one is selected because it gives adequate lighting levels and at the same time it yields 17% more energy savings. Additionally the second scenario has a much higher cost.

### 3.3.2. HVAC SYSTEM

A new HVAC system will replace the existing one. This will be a multi-zone VRV system. It includes three external and forty four internal units. The external units, VRV heat pumps, will be placed in the courtyard of the building. The internal units, ceiling mounted cassettes, will be installed in every office and will be controlled by their individual controllers so that every office has the desired internal air temperature.

In the server room on the first floor and at the canteen in the basement the existing air conditioning systems will not be replaced due to the special hydrothermal conditions of the former and particular requirements of the latter.

Into the large open space of the ground floor and second floor, two heat recovery ventilation devices (HRV), will be installed. The heat recovery ventilation systems will bring fresh air to 40% heat recovery reducing the energy requirements for heating and cooling. During night time when the outdoor temperature is below indoor temperature, the system will work at free cooling operation thus reducing the cooling demand in the morning of the next day.

The fresh air at the 1st, 3rd and the 4th floor will be ensured by openings equipped with fans and dampers and located on the outer walls, (low on north walls and high on the south). These openings will be able to close completely when are not needed. The circulation of fresh air will be used for cooling the envelope at night throughout the summer.

Renovating the old HVAC system with a new VRV system offers the ability of an autonomous operation locally in each indoor unit and savings in operating costs because of the higher EER and COP values. The old system has COP and EER values 1.7 and 1.5 respectively while the new one has a COP of 4.05 and EER of 3.61. The increased performance ratio of the new system will ensure less use of electricity resulting thus in greater energy efficiency.

The new VRV system has small refrigerant pipes which take up less space in shafts and ceilings and the VRV Cassette (62 cm x 62 cm) make the installation easy and without an extra need of reconstructing the fibre suspended ceiling.

In the following table are presented the technical characteristics and the units of each floor of the new HVAC system:

TABLE 19: HVAC SYSTEM - UNITS

Area	Units	Nominal Capacity (kW)		Performance Ratio		Type
		COOLING	HEATING	EER	COP	
OUTDOOR	1	28.0	31.5	3.84	4.45	VRV HEAT PUMP
OUTDOOR	1	33.5	37.5	3.73	4.31	VRV HEAT PUMP
OUTDOOR	1	50.0	56.0	3.40	4.03	VRV HEAT PUMP
GROUND FLOOR	1	4.5	5.0			VRV CASSETTE
GROUND FLOOR	9	2.2	2.5			VRV CASSETTE
GROUND FLOOR	1	7.1	8.0			VRV CASSETTE
FIRST FLOOR	11	2.2	2.5			VRV CASSETTE
SECOND FLOOR	1	2.2	2.5			VRV CASSETTE
SECOND FLOOR	4	2.8	3.2			VRV CASSETTE
SECOND FLOOR	1	4.5	5.0			VRV CASSETTE
THIRD FLOOR	4	2.2	2.5			VRV CASSETTE
THIRD FLOOR	4	2.8	3.2			VRV CASSETTE
FOURTH FLOOR	3	2.2	2.5			VRV CASSETTE
FOURTH FLOOR	4	2.8	3.2			VRV CASSETTE
FOURTH FLOOR	1	4.5	5.0			VRV CASSETTE
<b>AREA</b>	<b>UNITS</b>	<b>AIR FLOW RATE (m/h)</b>				<b>TYPE</b>
GROUND FLOOR	1	1,500				HRV UNIT
SECOND FLOOR	1	1,000				HRV UNIT

Table 20 presents the annual consumption with the existing HVAC system and the retrofit scenario. As can be seen, with the latter, energy savings of 58% can be achieved.

TABLE 20: ANNUAL CONSUMPTION BEFORE AND AFTER RETROFIT

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	24,065	50,184	10,107	21,079
<b>Savings (kWh)</b>	-	-	13,958	29,105
<b>Savings (%)</b>	-	-	58%	58%

The renovation of an existing HVAC system gives a great opportunity to increase the energy efficiency of the whole building and improves the internal conditions providing a comfortable environment to the users. The users will have the possibility to choose the precise room temperature through the individual room controller. The problems of the loud operating noise that the old machines were producing will be eliminated as the new system ensures a low operating noise. The indoor cassettes have a maximum noise power level of 51 dBA and maximum sound pressure level of 33 dBA. The old machines were distributing the air incorrectly straight to the users creating annoying thermal conditions. This will be eliminated as the new VRV Cassettes are selected to ensure a uniform 360° airflow distribution across the room without dead corners.

In addition the Heat Recovery Ventilation System (HRV), will modulate the temperature and humidity of incoming fresh air to match indoor conditions. Thus a balance is achieved between indoor and outdoor

conditions, enabling the cooling or heating load of the air conditioning system to be reduced up to 5%. Also the fresh air will be filtered and circulated throughout the offices. The HRV will continuously remove stale moist air from the building ensuring more suitable and healthy work conditions.

### 3.4. RENEWABLE ENERGY SOURCES

The building is located in a densely built area that offers limited opportunities for use of renewable energy sources. The potential integration of RES was investigated but only a small photovoltaic system can be integrated. The limiting factors are:

- Small scale wind turbines cannot be integrated because of the disturbance they cause on the neighbouring buildings and because of the reduced wind potential.
- A geothermal heat pump cannot be installed as the surrounding space of the building cannot accommodate the entrance of the drilling rig due to its size.
- Solar heating and cooling is not a potential option due to the limited sunlit space available for such installation.
- Biomass boiler has integration potential but its use would require extra equipment in the building just for heating. That is the building would have a biomass system for heating and a VRV for cooling. This would make the total HVAC installation more complicated, demanding more effort in operation and maintenance. Also it increases the cost and payback time of the renovation design compared to the proposed VRV system.

#### 3.4.1. PV GENERATION

In order to ensure that 50% of the consumed energy in the building is generated by renewable energy sources, a photovoltaic system will be installed on the building's roof. The building has two available areas (Figure 30) to place the photovoltaic system.



FIGURE 30: TWO AREAS AVAILABLE FOR THE PV SYSTEM INSTALLATION

A shading analysis was carried out by EnergyPlus in order to find the optimum place for installing the PV panels. The following pictures show fraction of the outside area of the building's surface that is illuminated by direct solar radiation in a certain time of the day.

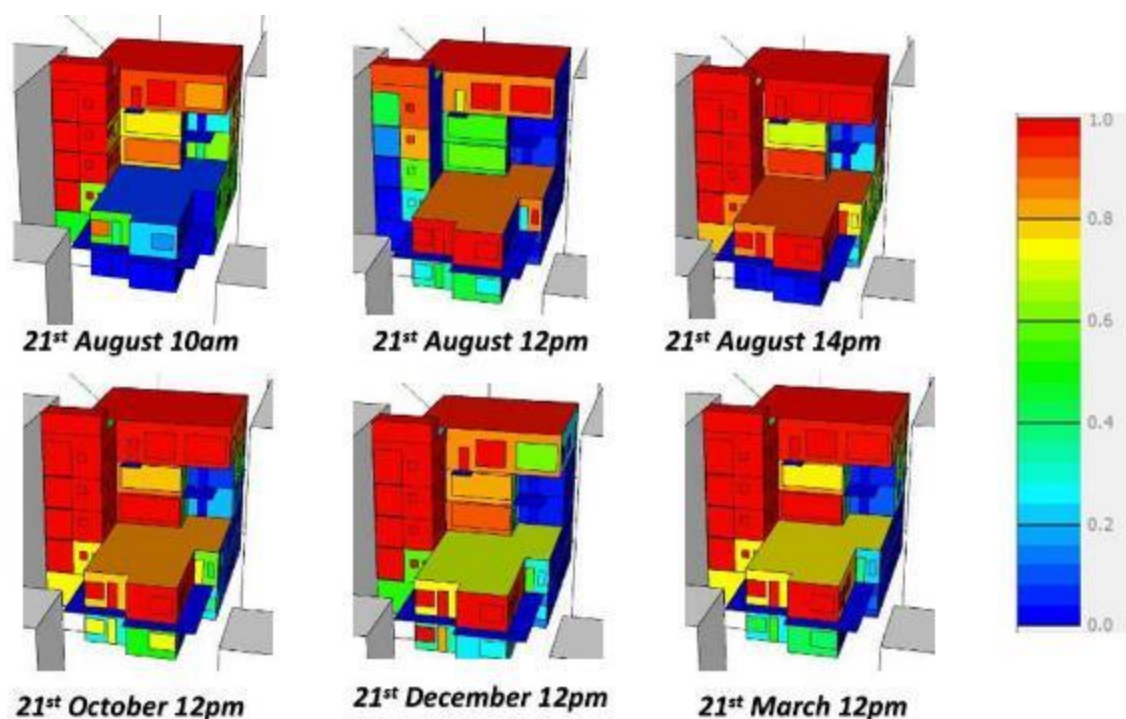


FIGURE 31: SUNLIT ANALYSIS OF SOUTH ELEVATION

The shadows which are created by the neighbouring buildings in Roof 2 during the day reduce the ratio of the area which receives solar radiation. For this reason, it was decided to install the PV panels only on Roof 1.

The selected roof can accommodate a photovoltaic system of total 15.26 kWp. The PV panels will be placed nearly due south with a fixed slope of 25°. The system will be connected to the low voltage grid via three-phase power.

The generated electricity will be supplied to the Utility (The Public Power Corporation), according to the Greek regulation "Net-metering". The prescribed procedure is the following. In each measurement cycle and billing, the electricity consumed by the building will be offset with the electricity generated by the photovoltaic system. In case there is excess energy this will be credited to the next billing period. At the end of the year the excess is cleared without compensation.

The picture below shows the PV panels on the roof.





FIGURE 32: PV PANELS INSTALLED ON THE ROOF

The PV system will consist of 48 (forty-eight) photovoltaic panels with nominal power of 318 Wp each. The connection to the low voltage grid will be done through 4 (four) DC/AC inverters with rated output of 3,800 Watt each and the total rated power of the PV system is 15.26 kWp.

The production of the PV system was estimated using PVGIS /3/, a software developed by The Joint Research Centre of the European Commission in ISPRA, Italy.

The monthly and annual solar radiation in the area based on the PVGIS database is presented in the following table.



TABLE 21: SOLAR RADIATION AT THE AREA OF ALIMOS - SOURCE: PVGIS DATABASE (KWH/ M<sup>2</sup>/MONTH) AT 25°

Month	Irradiation at inclination: (kWh/m <sup>2</sup> /month) 25° deg
JANUARY	91
FEBRUARY	95
MARCH	140
APRIL	168
MAY	193
JUNE	205
JULY	210
AUGUST	201
SEPTEMBER	178
OCTOBER	135
NOVEMBER	89
DECEMBER	79
<b>YEAR</b>	<b>1,784</b>

PVGIS set the Azimuth angle from -180° to 180°, East -180° and South 0°. The PV system will be installed at 30° west of south and 25° inclination from horizontal.

According to PVGIS, the 15.26 kW will produce **20,900 kWh** per year. In practice, this figure is expected to be exceeded by 15%. This argument is based on the recorded yield of the numerous PV installations in the area. However, in order to be on the safe side the PVGIS calculated value is used for the energy balance calculations and economic appraisal.

The monthly energy production and the PVGIS estimation are shown in the next figure.

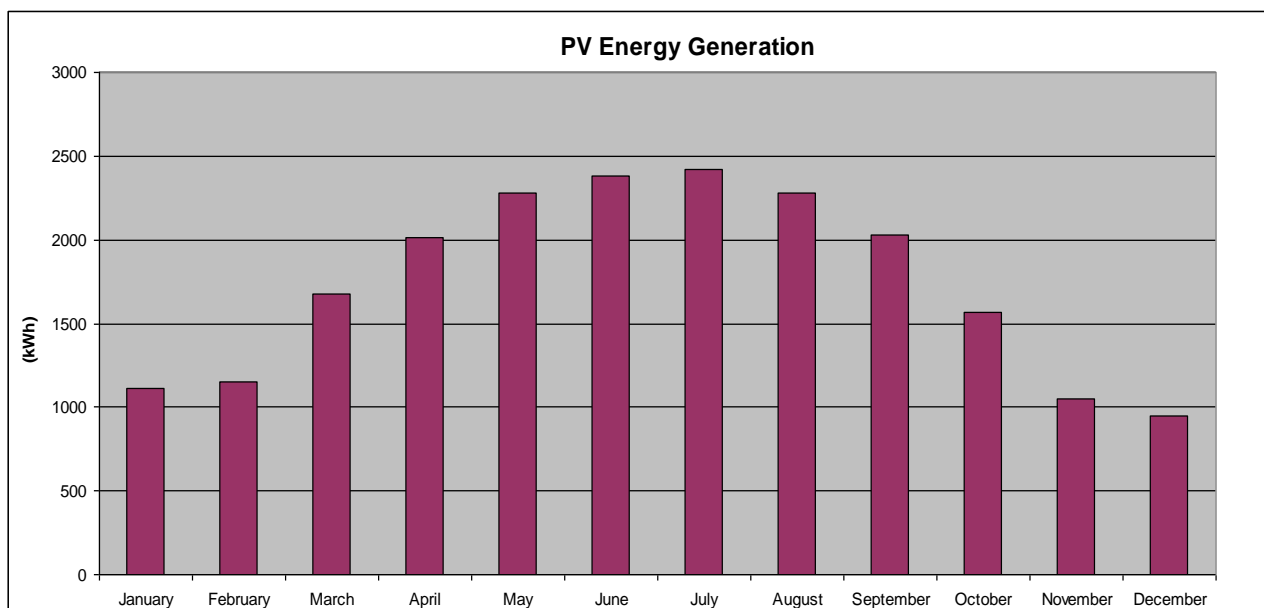


FIGURE 33: ENERGY INJECTED INTO GRID FROM THE PV SYSTEM

### 3.4.2. SOLAR THERMAL COLLECTORS

The building's needs for hot water are negligible and so there is no renovation plan regarding the use of solar thermal collectors.

## 3.5. ENERGY MANAGEMENT SYSTEM

In order to optimize the performance of the building's mechanical and electrical equipment such as, lighting, ventilation and HVAC system, an energy management system (BEMS) will be installed. The BEMS consists of one Touch Controller (LCD touch screen), power meters, electrical wiring equipment and a software. The BEMS will send and receive a total of 135 signals in digital and analogue format or pulse tones. The equipment which is connected to the BEMS is presented in Table 22.

TABLE 22: EQUIPMENT CONNECTED WITH BMS

Equipment	Units	Signal
VRV Heat Pump	3	digital
VRV Cassettes	44	digital
HRV Units	2	digital
Air Dampers	10	analogue
Lux Sensors	16	analogue
CO <sub>2</sub> Sensors	2	analogue
Anemometer	1	analogue
Ambient Sensor	1	analogue
Power Meters	6	pulse tone
On/Off Switches	50	analogue

---

The system will perform the following operations:

- Control each VRV, HRV and Air Damper unit separately to maintain in every office the desired internal air temperature stable
- Control each daylight sensor set point to take advantage of the natural lighting
- Daily and weekly schedule programming on/off of each VRV cassette and lighting zone in order to avoid excess use of them
- Record and storage the energy consumption of each VRV cassette separately so as to detect the energy intensive units
- A software with smart power management tools doing energy saving scenarios based on the outdoor temperature
- Automatically alert/Error via email in case of system failure in order to prevent excess energy consumption or a permanent damage on the systems
- Ventilation control depending on the indoor CO<sub>2</sub> levels so as to maintain the indoor air quality

The BMS will control, monitor and record data such as air temperatures, hours of operation and power consumption, of each VRV cassette separately. Also it will control, monitor and record the lighting energy consumption of each floor separately and the operation of each Lux sensor.

In all windows and doors will be placed an on/off touch connected with each VRV cassette operation. If a window is open, it will stop the operation of the corresponding VRV. The opening and closing of the openings will be recorded by the BEMS.

The BEMS layout is presented in Figure 34.

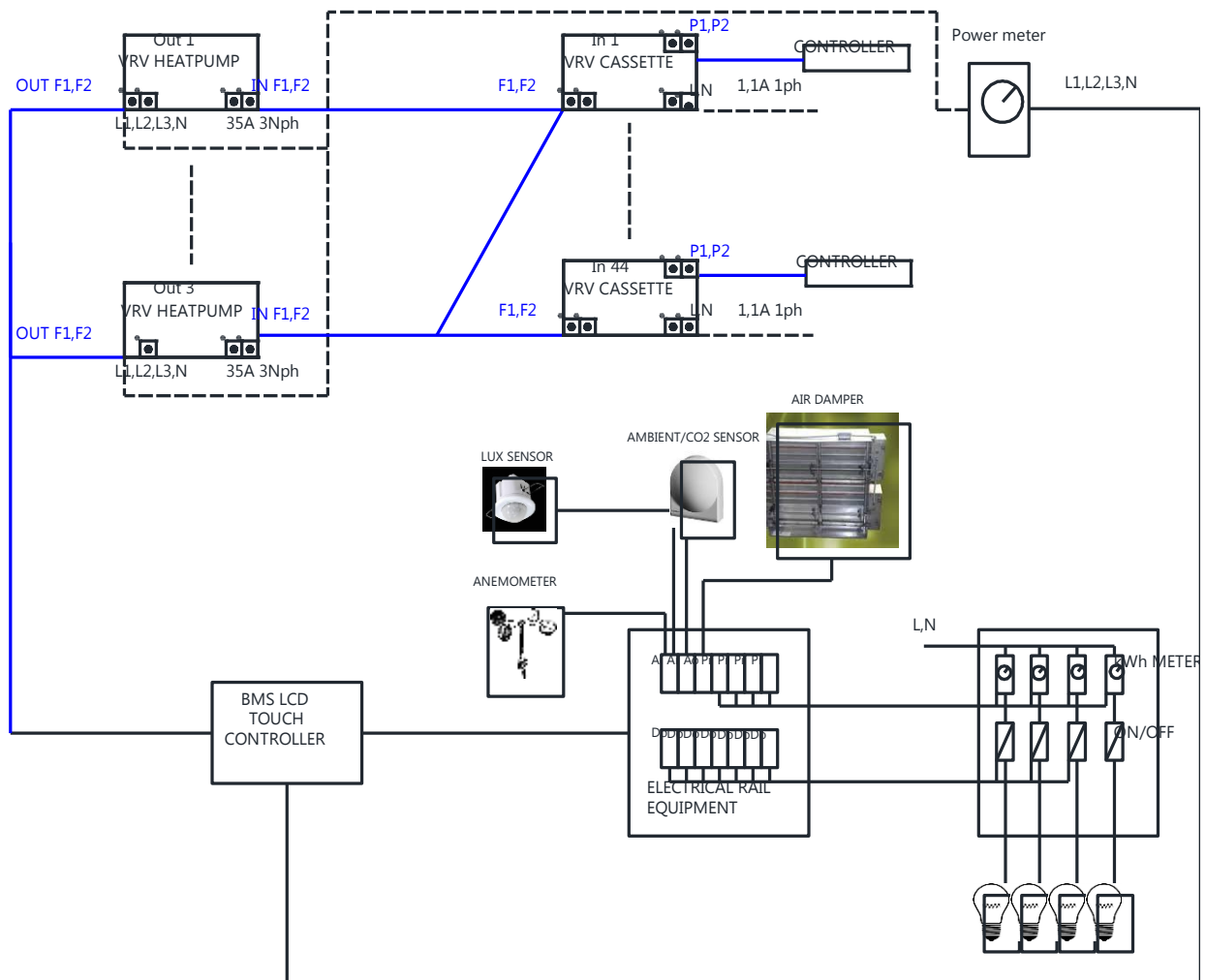


Table 23 presents the achievable savings, with the BEMS integration. The use of the BEMS ensures the standard internal conditions such as air temperature and lighting levels and prevents the excess use of energy.

	Before Retrofit			After Retrofit		
	Heating	Cooling	Lighting	Heating	Cooling	Lighting
Consumption (kWh)	24,065	50,184	37,713	12,273	35,131	32,999
Savings (kWh)	-	-	-	11,792	15,053	4,714
Savings (%)	-	-	-	49%	30%	12,5%

An additional benefit is that system's capacity to detect automatically the energy intensive units and produce energy saving scenarios with no need of human intervention. Finally, further cost reduction is achievable

due to the lower cost of the maintenance of the VRV systems as BEMS displays the units with the lower refrigerant and prevents permanent damages on the HVAC.

### 3.6. TOTAL IMPACT OF THE RENOVATION SCHEME

#### 3.6.1. ENERGY PERFORMANCE

The energy analysis of the building was carried out using the EnergyPlus v7.2 building simulation code. The building was described in due detail following the architectural drawings and results from the energy audit regarding lighting, equipment, and, building and systems operation profile. Also, the surrounding buildings were placed in the model in order to take into account the shading conditions created by them throughout the year. The specifications of the construction materials which were input to the software are according to the building studies (e.g. thermal insulation study) and the onsite inspections. Additionally, other parameters which are needed for the simulations such as internal environment (temperature, ventilation, and infiltration) and internal heat loads of users and devices were taken from the Greek regulation for the energy performance of buildings KENAK. The parameters used for the simulations are shown in ANNEX A-4, and A-5.

The weather data used in EnergyPlus for the simulation are taken from a meteorological station which is located at Ellinikon nearby Alimos {N 37° 54'} {E 23° 43'}, 15m above sea level. The comparison between the weather data from HNMS (Hellenic National Meteorological Service) and those that EnergyPlus uses are in good agreement.

Two scenarios were simulated. In the first scenario, the thermostat set points are according to the Greek regulations, namely, 20 °C for heating and 26 °C for cooling. The second scenario is more realistic regarding the building's operational profile and the thermostats' set-points are set at 22 °C for heating and 24 °C for cooling. These values result from the site inspection.

The consumptions for the first scenario, second scenario and the actual one from Utility invoices are displayed below. It is noted that the heating and cooling consumptions are calculated based on the cooling and heating demands resulted from EnergyPlus and considering that COP and EER of the building's air conditioning systems are equal to 1.7 and 1.5 respectively. This is in line with the national regulation, KENAK, for old air-conditioning systems that are not properly maintained.

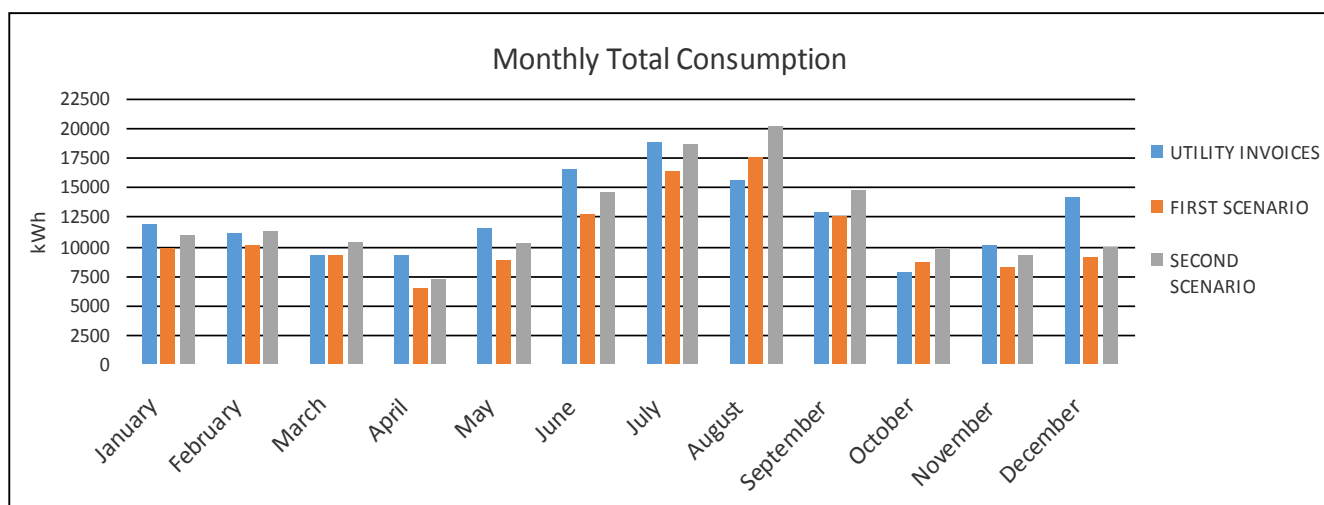


FIGURE 35: COMPARING ENERGYPLUS RESULTS WITH UTILITY INVOICES MONTHLY CONSUMPTIONS

TABLE 24: ANNUAL TOTAL ELECTRICITY CONSUMPTION

Utility (kWh)	1 <sup>st</sup> Scenario (kWh)	2 <sup>nd</sup> Scenario (kWh)
148,613	129,125	147,072

The actual consumption which results from the Utility's bills is 148,613 kWh, (excluding elevators' consumption)<sup>2</sup>. After comparing all three consumptions, we conclude that the ideal and the realistic consumption is lower than the actual one by 13% and 1% respectively. The difference between the realistic and the actual consumption is negligible and so all the interventions will be applied on the second scenario's model.

The following table shows how each intervention affects the energy consumption of the building. The changes are displayed separately for heating, cooling, lighting and total in order each intervention to be evaluated in a very detailed way.

The calculations are based on the optimum choices regarding all the interventions as they presented in paragraphs 3.2 to 3.5. The selected renovation plan is the following:

- Add external insulation of 5cm thickness and conductivity  $\lambda$  (k) equal to 0.032 W/mK
- Replacement of the windows with total U-value 1.8 W/m<sup>2</sup>K, Solar Factor of 42% and Light Transmission 66%
- Add external movable louvers
- Replacement of all lamps with LEDs

<sup>2</sup> The HDD and CDD which are calculated for the weather station of Ellinikon (nearby to Alimos) under the Greek regulation diverge from those which are used from EnergyPlus only by 6% and 3% respectively. More specific the HDD according to Greek regulation are 944 and to EnergyPlus are 1,010, and the CDD according to Greek regulation are 1,111 and to EnergyPlus are 1,079. The normalization of the actual consumption of the three years increases the average value by 4.5%, from 148,613 kWh to 155,449 kWh. Due to the insignificant change, the real consumption was compared directly with the calculated one without a degree day correction.

- Replacement of the installed A/C with VRV (Ceiling-Mounted Cassette) and VHR (ventilation with 40% heat recovery)
- Add night ventilation of 15 ACH
- Add solar gains circulation
- Add BEMS for the whole building in order to control, monitor and record the energy consumption
- Install PVs on the roof 15.26 kWp

TABLE 25: ENERGY SAVINGS FROM EACH INTERVENTION

		HEATING	COOLING	LIGHTING	ELECTRICITY
		ENERGY SAVINGS [%]	ENERGY SAVINGS [%]	ENERGY SAVINGS [%]	POWER [kWh/year]
BUILDING ENVELOPE	<b>External Insulation</b> U-value= 0.032 W/mK d= 5 cm	19 ↓	2 ↑	-	
	<b>Windows Low-e,</b> U-value= 1.8 W/mK	22 ↓	3 ↑	-	
	<b>Shading devices</b> with schedule	-	22 ↓	-	
HVAC	<b>VRV system</b> COP= 4.05 EER= 3.61	58 ↓	58 ↓	-	
	<b>BEMS</b> standard setpoints	49 ↓	30 ↓	-	
	<b>Night Ventilation</b>	-	21 ↓	-	
	<b>Cross Mixing</b> solar gains	1 ↓	-	-	
LIGHTING	<b>LED</b>	-	-	51 ↓	
	<b>BEMS</b> control for daylighting use	-	-	13 ↓	
RES	<b>PV</b> on the roof 15.26 kWp				20,900

As the results show some interventions have contradictory effects on heating and cooling consumption (e.g. external insulation) and so the final decision cannot be taken without taking into consideration the absolute effect on the total energy consumption. At the same time, the impact that each intervention has on other parameters like internal conditions, users' comfort, etc. has to be evaluated too.



The following table shows the accumulative effect on the energy consumption of the building from the implementation of the renovation plan. The changes are displayed separately for heating, cooling, lighting and total in order the renovation plan to be evaluated in different phases.

TABLE 26: ACCUMULATIVE ENERGY SAVINGS FROM THE INTERVENTIONS

ENERGY	Heating		Cooling		Lighting		Total	
	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]
INITIAL	24,065	-	50,187	-	37,713	-	111,965	-
INSUL	19,548	-19%	51,229	2%	37,713	0%	108,490	-3%
WIND-INSUL	17,216	-12%	52,930	3%	37,713	0%	107,858	-1%
INSUL-WIND-CROSS	16,965	-1%	52,930	0%	37,713	0%	107,607	0%
INSUL-WIND-CROSS-SHAD	16,965	0%	41,542	-22%	37,713	0%	96,219	-11%
INSUL-WIND-CROSS-SHAD-NV	16,965	0%	33,518	-19%	37,713	0%	88,195	-8%
INSUL-WIND-CROSS-SHAD-NV-VRV	7,121	-58%	13,927	-58%	37,713	0%	58,761	-33%
INSUL-WIND-CROSS-SHAD-NV-VRV-LIGHTING	7,121	0%	13,927	0%	18,479	-51%	39,527	-33%
INSUL-WIND-CROSS-SHAD-NV-VRV-LIGHTING-BEMS	3,803	-47%	8,356	-40%	16,169	-12%	28,328	-28%

INSUL: extrenal insulation	NV: night ventilation
WIND: windows	VRV: new system
CROSS: crossmixing solar gains	LIGHTING: led
SHAD: shading	BEMS: VRV and Lighting control

These data show how the different interventions interact with each other and how they influence the energy consumption generated from different uses. This information is very important because the final condition of the building is not just the sum of all different savings, and so, it is not easy to be estimated without the appropriate simulations.

### 3.6.2. ENVIRONMENTAL PERFORMANCE

The following table shows the initial and the final consumption after implementing all the proposed interventions in the building.

TABLE 27: ENERGY CONSUMPTION BEFORE AND AFTER RENOVATION PLAN

ENERGY	Heating		Cooling		Lighting		Total	
	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]
INITIAL	24,065	-	50,187	-	37,713	-	111,965	-
FINAL	3,803	-84%	8,356	-83%	16,169	-57%	28,328	-75%

It can be noticed in the previous table that the design set target of at least 70% energy savings is satisfied. Also, as it was expected the energy consumption for cooling is higher than the corresponding for heating and this is because of the building use, the operational profile and climate zone. Additionally, the energy consumption for lighting has a large share of the total one.

After the renovation the energy consumption is finally reduced by 20,262 kWh for heating, 41,831 kWh for cooling, 21,544 kWh for lighting and 83,637 kWh in total.

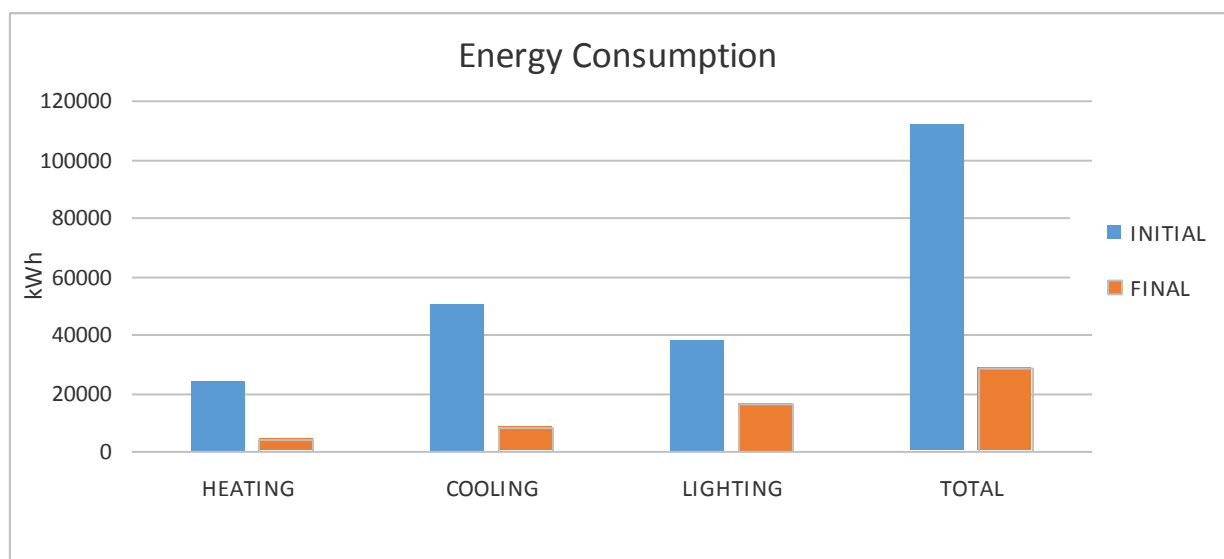


FIGURE 36: COMPARISON OF ENERGY CONSUMPTION FOR EACH USE

The results were also assessed in terms of primary energy and CO<sub>2</sub> emissions considering the following conversion factors which are taken by the Greek regulation for the energy performance of buildings:

- electricity to primary energy – 2.9
- electricity to CO<sub>2</sub> emissions – 0.989 kg/kWh

TABLE 28: PRIMARY ENERGY CONSUMPTION AND CO<sub>2</sub> EMISSIONS BEFORE AND AFTER RENOVATION PLAN

	Heating		Cooling		Lighting		Total	
	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]
INITIAL (primary energy)	69,788	-	145,543	-	109,367	-	324,698	-
FINAL (primary energy)	11,028	-84%	24,233	-83%	46,891	-57%	82,152	-75%
INITIAL (CO <sub>2</sub> emissions) [kg CO <sub>2</sub> ]	23,800	-	49,635	-	37,298	-	110,733	-
FINAL (CO <sub>2</sub> emissions) [kg CO <sub>2</sub> ]	3,761	-84%	8,264	-83%	15,991	-57%	28,017	-75%

The previous table shows the comparison regarding consumption and the savings in primary energy and CO<sub>2</sub> emissions before and after the renovation. The achieved savings are 75% in total primary energy and CO<sub>2</sub> emissions which are 242,546 kWh and 82.72 tons of CO<sub>2</sub> emissions respectively.

Also, the proposed PV system produces 20,900 kWh/year which means that 75% of the total end use annual electricity consumption will be covered by renewable energy sources.

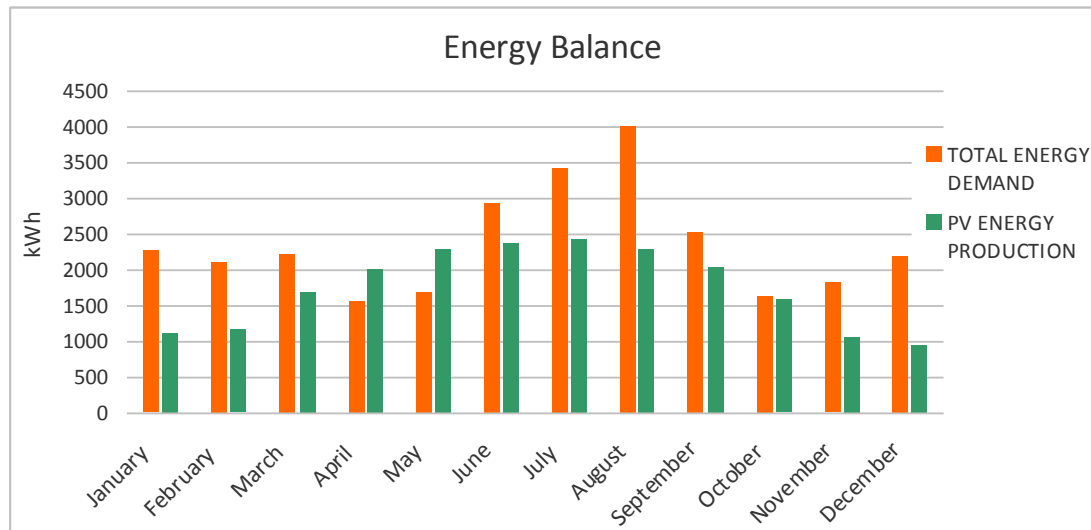


FIGURE 37: ENERGY INJECTED INTO GRID FROM THE PV SYSTEM

As it is shown on the graph above, the energy production of the PV system in months April and May overcomes the corresponding energy demand. According to Net Metering procedure the excess energy of these two months will be credited to the next months.

**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** shows the comparison between the current energy demand and the one after the PV installation. As it is noticed for four months throughout the year the demand is almost zero.

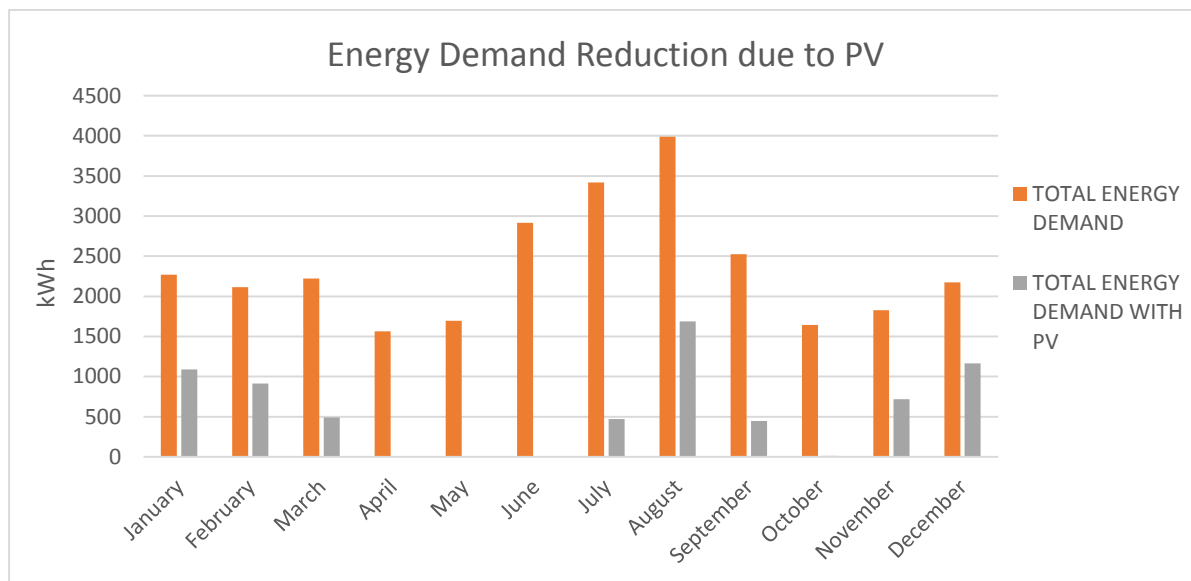


FIGURE 38: ENERGY DEMAND WITH AND WITHOUT PV

After subtracting the energy which is produced by the PV system annually from the final demand of electricity, there is a further decrease of the primary energy to 21,542 kWh which means that the total savings are 303,156 kWh. This leads to supplementary savings of the CO<sub>2</sub> emissions as well by 20.67 tons/year and in total by 103.37 tons/year.

## FINAL RENOVATION

<b>Building Envelope</b>	<ul style="list-style-type: none"> <li>External insulation</li> <li>Low-e glazing windows</li> <li>External Shading</li> <li>Solar gains circulation</li> <li>Natural and Night Ventilation</li> </ul>	Primary Energy Consumption for Heating	10.01 kWh/m <sup>2</sup>
		Primary Energy Consumption for Cooling	22.01 kWh/m <sup>2</sup>
		Primary Energy Consumption for Lighting	42.59 kWh/m <sup>2</sup>
		Energy production from PV	18.98 kWh/m <sup>2</sup>
<b>Energy Systems</b>	<ul style="list-style-type: none"> <li>VRV System / VAM Heat Recovery</li> <li>LED lighting with Lux sensors</li> <li>BEMS</li> </ul>	Primary Energy Savings from Interventions	75%
		Energy Savings with PV	73.7%
		Total Primary Energy Savings	93.4%
<b>RES</b>	<ul style="list-style-type: none"> <li>PV system</li> </ul>		

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## 4. ECONOMIC EVALUATION OF THE PROPOSED RENOVATION SCHEME

### 4.1. ASSUMPTIONS AND COST FIGURES

The cost of the interventions is estimated based on current market prices of the equipment and the installation works. Special meetings with suppliers were held to present the project and request offers for the preliminary renovation design. Offers were collected and assessed.

For each intervention, the cost has been calculated as the sum of costs for equipment, installation, operation and maintenance. These values have been organised in an Excel file prepared by Sinloc, a partner of the CERTUS consortium /4/. ANNEX A-8, gives the cost information.

The economic appraisal of the renovation design was performed by means of a tool produced by ETVA VIPE, also a partner of the consortium. A detailed description of the tool is presented in /4/. The appraisal can be performed for each intervention separately and, for the whole design. The tool also allows examination of various financing schemes ranging from single financing source to multiple, combining bank loans, ESCOs, subsidies, municipality's own equity.

As output, it gives the NPV, IRR and payback time for each financing source and for the total investment. Also the cash flow over the examined period is given.

The data used for the calculations are tabulated below (Table 29).

TABLE 29: DATA FOR THE ECONOMIC EVALUATION OF INTERVENTIONS

PARAMETER	INTERVENTION								
	Insulation	Windows	Cross Solar Heat	Shading	VRV	N. Vent.	Lighting	BEMS	PV
Cost of intervention (€)	83,505	55,350	1,230	25,000	74,784	5,535	18,905	20,910	26,273
O&M cost (€)(*)	0	0	1,634	0	32,671	3,267	2,234	16,335	6,534
Extraordinary maintenance cost (€) (*)	0	2,019	0	1,992	11,951	1,352	0	3,134	5,976
Cost of energy before( €)	20,154	20,154	20,154	20,154	20,154	20,154	20,154	20,154	20,154
Cost of energy After (€)	18,524	19,472	20,110	18,166	12,402	18,406	16,280	14,378	16,391
Change of energy cost over examined period (**)	1%	1%	1%	1%	1%	1%	1%	1%	1%
Equipment efficiency drop over examined period	0%	0%	0%	0%	20%	20%	0%	0%	20%
Interest rate	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
Discount rate	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%
Average inflation rate over examined period	2%	2%	2%	2%	2%	2%	2%	2%	2%

(\*) This is the cost over the lifetime of the intervention that is taken equal to 25 years for all except for the lighting that is 10 years.

(\*\*) The examined period is 25 years for all interventions except of lighting which is 10 years.

## 4.2. RESULTS

The Table below (Table 30) presents the payback time, NPV and IRR calculated for each intervention separately and for the complete design (all interventions).

TABLE 30: ECONOMIC EVALUATION OF INTERVENTIONS

	Insulation	Windows	Cross Solar Heat	Shading	VRV	N. Vent.	Lighting	BEMS	PV	ALL Interventions
Payback period (years)	23	23	23	12	11	3	5	3	7	20
NPV	-47,386	-42,298	-1,230	9,159	26,315	20,257	12,451	69,788	27,668	-63,363
IRR	-1.05%	-4.1%	0.0%	6.79%	6.88%	29.49%	15.15%	25.52%	12.21%	1.71%

The following figure compares the payback period of each intervention as a separate investment and the combination of all the interventions.

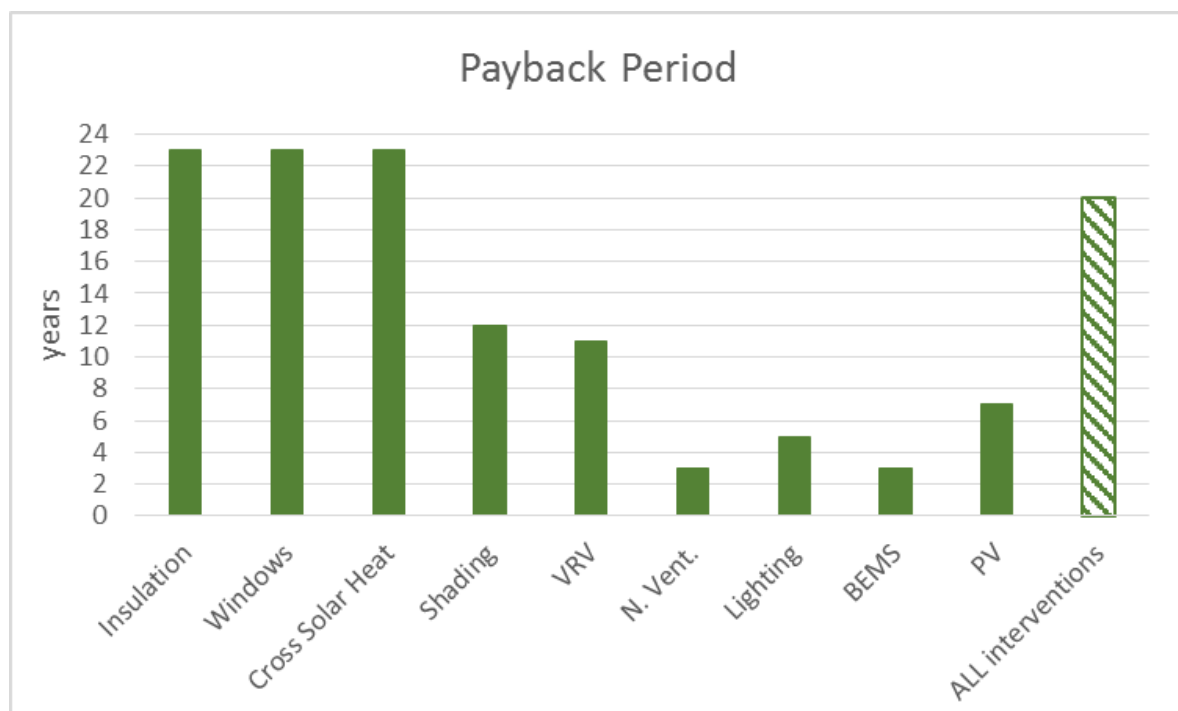


FIGURE 39: PAYBACK PERIOD FOR EACH INTERVENTION

As can be seen from the figure above if all interventions are applied they have a payback time of 18 years. The interventions relevant to the envelope have lengthier payback times and so they increase the overall payback time. Although these envelope interventions have side benefits such as the prolonged lifetime of the building and the increase of asset value, the current economic appraisal focuses strictly on the annual balance of costs and savings. Thus at the period of 25 years (the common expected life span for building



interventions) the net present value of the building envelope interventions is negative. This means that unless there is a suitable subsidy these interventions are not currently financially attractive. However, in the future this situation may change if the building needs or the market conditions change.

The economic appraisal of three alternative scenarios was carried out without the building envelope improvement. The first one excludes only the external insulation, the second one only the replacement of the glazing and the third one excludes both interventions. The comparison of the scenarios with the initial renovation scheme is displayed in the following Table.

TABLE 31: COMPARISON OF ALTERNATIVE RENOVATION SCENARIOS

	Heating [kWh]	Cooling [kWh]	Total [kWh]	Percentage Of Energy Increase [%]
<b>Complete Renovation Scheme</b>	3,803	8,356	12,159	-
<b>Scenario 1</b> (without external insulation)	4,527	8,178	12,705	4 %
<b>Scenario 2</b> (without glazing replacement)	4,338	8,167	12,505	3 %
<b>Scenario 3</b> (without external insulation and glazing replacement)	5,340	8,186	13,526	10 %

Table 31 shows that the increase of the energy consumption in the three alternative scenarios is not significant. An increase in the insulation causes heating demand to decrease but contrarily it increases cooling demand. Thus the annual balance is lower but not significantly.

The economic evaluation of these alternative scenarios is shown in Figure 40 and Figure 41.

As can be seen, the high cost of the external insulation and windows replacement combined with the low increase in energy needs make scenario 3 the most feasible one.

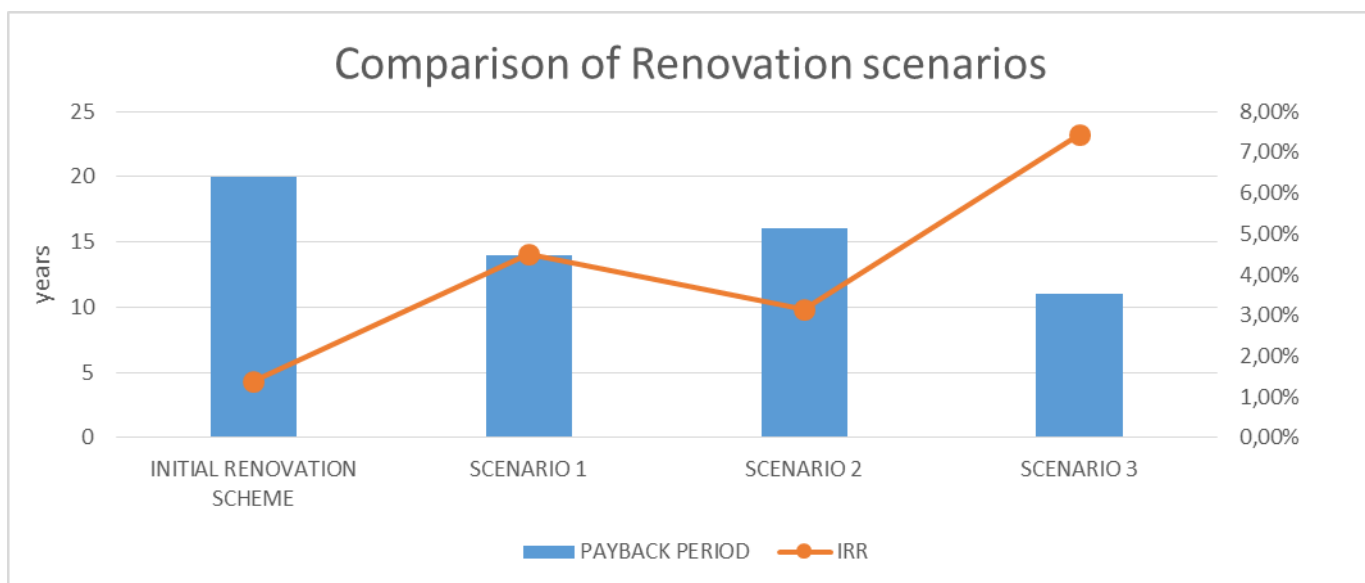


FIGURE 40: PAYBACK PERIOD AND IRR FOR ALL RENOVATION SCENARIOS

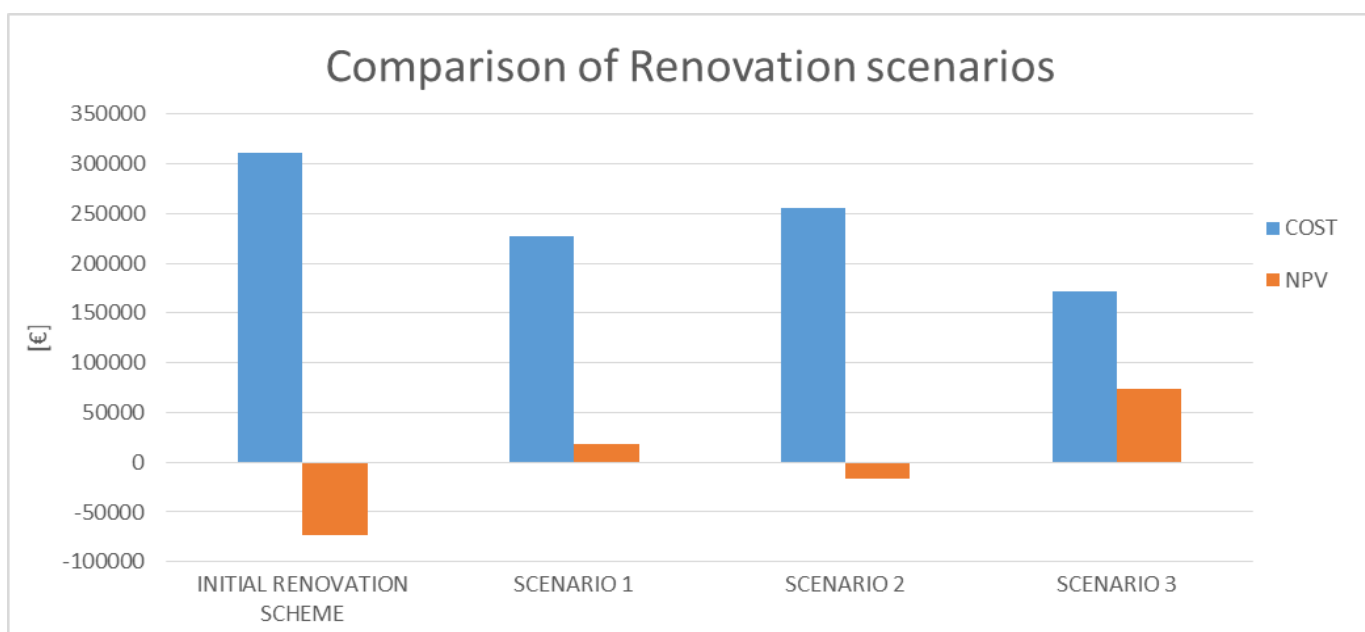


FIGURE 41: COST AND NPV FOR ALL RENOVATION SCENARIOS

The following Table (Table 32), summarises the results of the 4 scenarios.

TABLE 32: COMPARISON OF ALTERNATIVE RENOVATION SCENARIOS

Scenario	Energy SAVINGS (%)	Res Contribution (%)	Cost (€)	Payback Period (years)
<b>Complete Renovation Design</b>	75.0	74.0	310,430	20
<b>Scenario 1</b> (without external insulation)	74.0	72.0	227,438	14
<b>Scenario 2</b> (without glazing replacement)	74.5	73.0	255,593	16
<b>Scenario 3</b> (without external insulation and glazing replacement)	73.0	70.0	172,088	11

Even with scenario 3, the energy consumption for heating, cooling and lighting is reduced by 73% and so, the renovation energy target requiring reduction over 70% is achieved. At the same scenario 3, the RES contribution is 70% of the remaining energy needs and so the target which is at least 50%, is satisfied.

Therefore, if the building envelope improvement cannot be funded under the current conditions, they can be excluded from the renovation plan. Probably they can be implemented at a later time or when economic conditions are more favourable.

## B. ENVIRONMENTAL SERVICES OFFICES

### 5. BUILDING GENERAL DESCRIPTION

#### 5.1. LOCATION

The building houses the environmental and hygiene services of the Municipality. It is one-floor building constructed in 1986. It is surrounded by a large open area that serves as parking lot and vehicle repairing facility.



FIGURE 42: ALIMOS ENVIRONMENTAL SERVICES OFFICE – MAIN FAÇADE OF THE BUILDING (NORTHEAST SIDE)

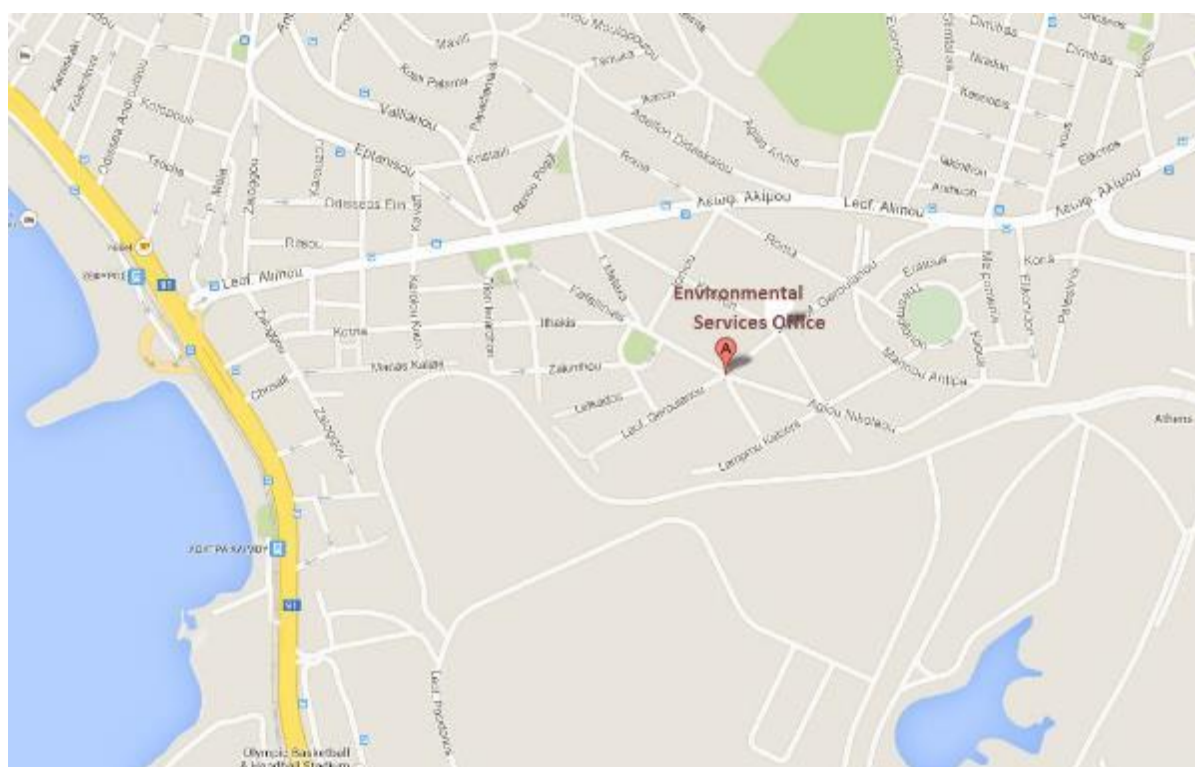
The neighbouring buildings are in sufficient distance so that there is no important shadowing and the building enjoys full sunshine.

The coordinates of the building are shown in Table 33.

**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** Figure 43 and Figure 44**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** present the location in the map and Google Earth view.

TABLE 33: LOCATION DATA OF THE BUILDING

Address	Kefallinias & Geroulanou, 174 55 Alimos, Greece
Coordinates	37° 54' 18.80'', 23° 43' 41.30''



**FIGURE 43: ENVIRONMENTAL SERVICES OFFICE (MAP)**



**FIGURE 44: ENVIRONMENTAL SERVICES OFFICE FROM GOOGLE EARTH**



## 5.2. SHAPE AND ORIENTATION

The building has an orthogonal shape and is elongated along the E-W axis with 33° deviation from North. Table 34 gives the orientation of the façades relative to north, considering north at 0°.

TABLE 34: ORIENTATION OF THE BUILDING

Orientation	Angle "c"
NE	33°
SE	123°
SW	213°
NW	303°

The following figures presents the plan view of the ground floor as well as the cross section of the building. See ANNEX B-1 for the rest drawings of the building.

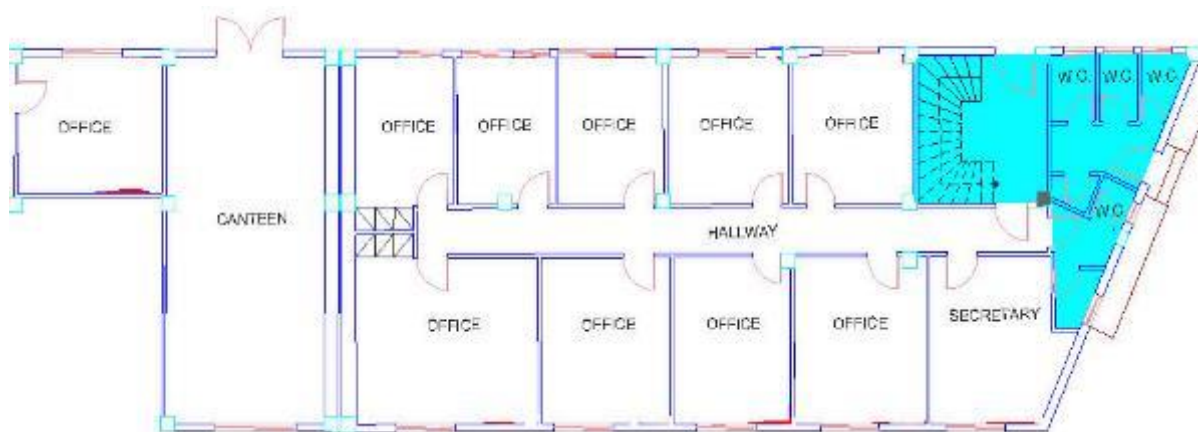


FIGURE 45: GROUND FLOOR

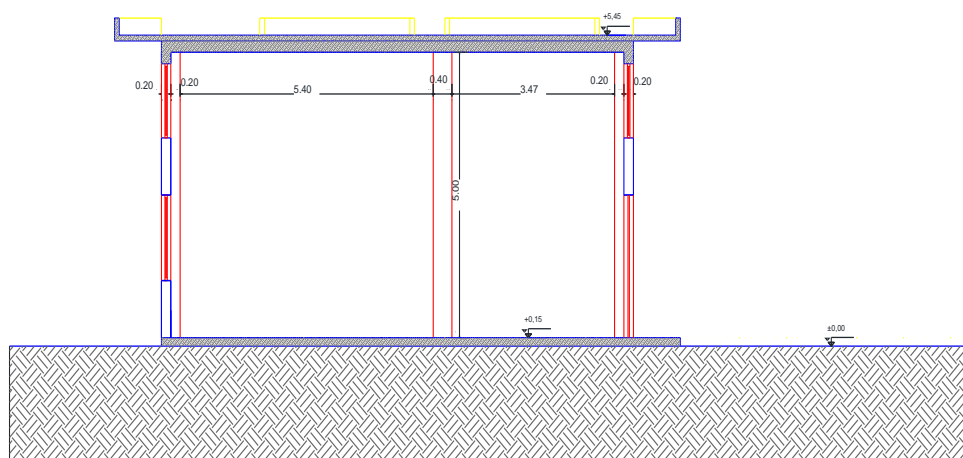


FIGURE 46: CROSS SECTION

Figure 47 shows the orientation of the building facades, the main façade and the entrance of the building is in the northeast side.



FIGURE 47: ENVIRONMENTAL SERVICES OFFICE – ORIENTATION OF THE BUILDING FACADES

### 5.3. AREA AND VOLUME

The surface area and volume of the building are 446 m<sup>2</sup> and 1,518 m<sup>3</sup> respectively. The total treated area is 311 m<sup>2</sup> with a corresponding volume of 1,086 m<sup>3</sup>. Table 35 below gives the surface area and volume.

TABLE 35: SURFACE AREA AND VOLUME

Surface areas in m <sup>2</sup> / Volume in m <sup>3</sup>			
<b>Total Area :</b>	446 m <sup>2</sup>	<b>Total volume:</b>	1,518 m <sup>3</sup>
<b>Heated surface:</b>	311 m <sup>2</sup>	<b>Heated volume:</b>	1,086 m <sup>3</sup>
<b>Air-conditioned surface:</b>	311 m <sup>2</sup>	<b>Air-conditioned volume:</b>	1,086 m <sup>3</sup>
		<b>Ground floor gross height:</b>	3.2 m

### 5.4. CURRENT USE

The Environmental Services Office consists of the main building with a ground floor and a basement and two separate small buildings with the following arrangement and uses:

- Ground floor: consists of offices and houses various public services. It also houses the canteen serving the employees and visitors.
- Basement: The basement is used as a warehouse.
- Building 1: houses a registration/protocol office.
- Building 2: is used as a guardhouse.



A parking area for municipality's refuse collector trucks is located on the northeast and northwest sides of the building. The total area of the free space around the building is 2,000 m<sup>2</sup>.

The building operates the weekdays, all year round, with the following schedule:

- Offices and Building 1: 7:00 – 15:00
- Building 2 - 24 hours per day

The occupation profile of each area is as follows:

TABLE 36: OCCUPATION PROFILE

Zone	Floor	Number of Employees	Number of Visitors/day	Hours/day of work	Hours/day of visit
1	Offices	16	10	8	1
2	Canteen	1	-	8	-
3	Garage Office	1	-	8	-
4	Building 1	1	-	8	-
5	Building 2	1	-	24	-
6	Basement	-	-	-	-



FIGURE 48: ENVIRONMENTAL SERVICES OFFICE – LAY-OUT

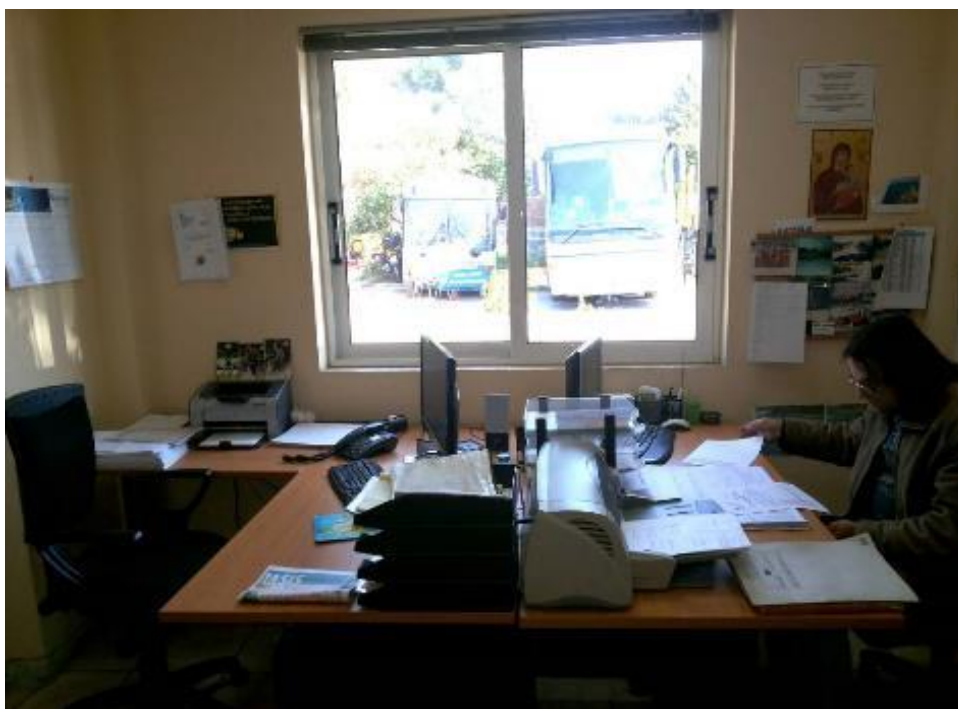


FIGURE 49: ENVIRONMENTAL SERVICES OFFICE–OFFICE ROOM

## 6. CURRENT BUILDING CONDITIONS

### 6.1. CONSTRUCTIVE BUILDING CHARACTERISTICS

This is a detached building with a construction system typical for the period and region.

#### 6.1.1. ENVELOPE ELEMENTS

The walls consist of double brick and reinforced concrete for the load bearing structure. The walls are insulated with 5 cm of extruded polystyrene placed in between the two brick layers. The roof slab is insulated with 6 cm extruded polystyrene while there is a mineral fibre suspended ceiling in the office space.

#### 6.1.2. WINDOWS

In all working areas there are opening windows with double glazing in aluminium frame.

The design overall U-value of the building envelope is 0.697 W/m<sup>2</sup>K. The following Table reports the U-values of the building envelope components as they are calculated in the thermal insulation study of the building.

TABLE 37: ENVIRONMENTAL SERVICES OFFICE – U-VALUES

Element	Material	U-Value (W/m <sup>2</sup> K)
Wall	Double brick with 5 cm insulation in between	0.587
Load bearing structure	Reinforced concrete	0.627
Basement	Flat Reinforced concrete	0.627
Roof	Flat reinforced concrete with 6 cm insulation	0.450
Windows	Double glazing in aluminium frame	3.490

### 6.1.3. AIRTIGHTNESS AND PATHOLOGIES

The envelope has many thermal bridges due to the type of wall construction as described above and these problems have not been addressed adequately in the thermal study.

The windows and the doors of the building do not present any problems of air tightness and the building doesn't present other major pathologies.

## 6.2. ENERGY SYSTEMS

### 6.2.1. HVAC

Split unit air conditioning systems are used for heating and cooling the building via electricity. The garage office uses an oil radiator for heating. The total installed capacity of the A/C systems in the building is 49.81 kW.



FIGURE 51: SPLIT A/C SYSTEM – EXTERNAL UNIT MOUNTED AT THE ROOF



FIGURE 52: SPLIT A/C SYSTEM – INTERNAL UNIT MOUNTED ON THE WALL

TABLE 38: INSTALLED CAPACITY OF THE AC SYSTEMS

System	Power (kW)	Units	Total Power (kW)
INCLIMA 12TP	3.52	1	3.52
FUJICO WSH-229BE	6.45	1	6.45
INCLIMA 18TP	5.28	2	10.56
INCLIMA 9TP	2.64	6	15.84
INCLIMA 18TP	5.28	1	5.28
INCLIMA 12TP	3.52	1	3.52
Oil Radiator	2	1	2
INCLIMA 9TP	2.64	1	2.64
<b>Total:</b>			<b>49.81</b>

The total installed capacity of the A/C systems in the building is 49.81 kW.

However, because of the age and the inadequate maintenance of the devices the current performance of the A/C equipment is considered to be quite reduced around 1.7 for heating and 1.5 for cooling, according to the regulation for energy efficiency, KENAK.

## 6.2.2. LIGHTING

The lighting system is mainly constituted by fluorescent T8 lamps with magnetic ballast. The total installed capacity is 3,866 W. All types of lighting that the building uses are presented below:

Type A: Ceiling lamp, square, 60 cm x 60 cm, with 4 lamps T8 fluorescent 18 W (4x18 W), magnetic ballast, condenser and compensation with reflector and louver. This light type is the most common in the building, located in offices.

Type B: Ceiling lamp, with 2 lamps T8 fluorescent of 36 W (2x36 W), length 120 cm, body with reflector and louver. This light type is located in the hallway.

Type C: Circular lamp with one lamp of 35 W, located in WC.

Type D: Oval wall lamp with one lamp of 40 W, located in the external walls of the building.

Type E: High-Pressure Sodium Vapour lamp 250 W, located outdoors.

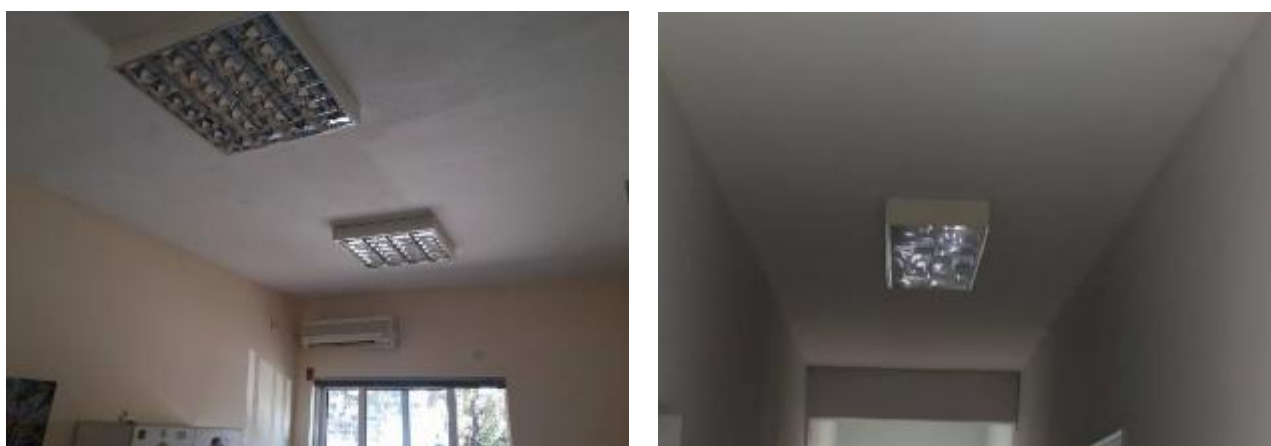


FIGURE 53: TYPE A, B - FLUORESCENT CEILING LAMP 4X18 W AND 2X36 W

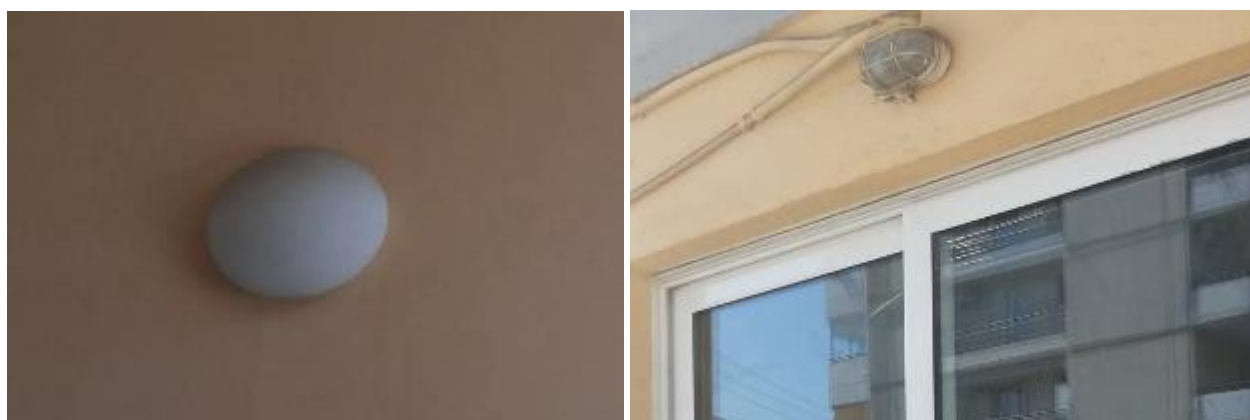


FIGURE 54: TYPE C, D - CIRCULAR LAMP 35 W AND OVAL WALL LAMP 40 W



### 6.2.3. OTHERS

Other electrical loads are generated from ICT equipment such as PC units, printers, copy machines and other electrical devices. Their total power is 9,970 W.

TABLE 39: ELECTRICAL LOADS PER USE

Devices	Total Power (W)
PC	3,000
Printer	120
Copy machine	1,600
Canteen appliances	8,690
<b>Building Total:</b>	<b>9,970</b>

In addition, there is a large electrical consumption which is not related to the building's operation but is included in the Utility invoices.

That consumption refers to a water pump, which is located in the northwest side of the parking area and is used for watering the green areas of the Alimos Municipality. The pump has 7.5 kW power and works 8 hours per day. The water pump's total annual consumption is around 21,900 kWh.



FIGURE 55: THE 7 KW WATER PUMP

## 6.3. ENERGY CONSUMPTION AND ENERGY GENERATION

### 6.3.1. ELECTRICITY CONSUMPTION

All energy needs of the building are covered with electricity. The building receives electricity in Low Voltage. Based on the Utility invoices of the last 3 years and after subtracting the water pump's annual consumption, the average annual consumption of the building is 35,478 kWh and the average annual total specific

consumption is 114 kWh/m<sup>2</sup>. The monthly electricity consumption for the period 27/12/2010 - 18/12/2013 based on the monthly PPC invoices (water pump's consumption is subtracted) is depicted in the following graph.

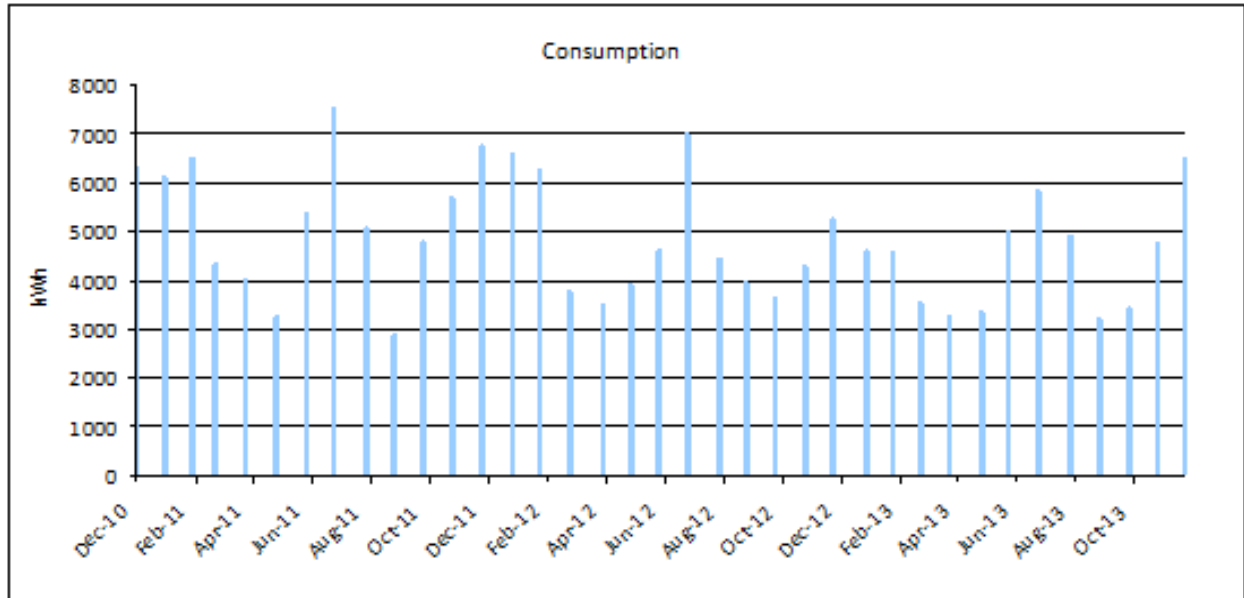


FIGURE 56: MONTHLY ELECTRICITY CONSUMPTION DURING THE PERIOD 2011-2013

As it can be seen from Figure 56 the higher consumption occurs during August and is due to cooling. This is in agreement with the building use and operation profile, as well as the warm climate prevailing in the area. More specifically, the cooling peak is much higher due to the fact that during summer, the demand occurs during the warmer period of the day when the solar intensity and outdoor temperatures are high. Contrarily, during the heating period the highest demand occurs at night when the building is not operating. In spring and autumn, the energy consumption reaches its lowest point as there is no need for heating or cooling.

The electricity consumption was disaggregated between uses by means of EnergyPlus building simulation code. The building model and its equipment and occupant profile are detailed in chapter 3.6.1, and ANNEXES B-2, B-3 and B-4. As shown on the next Figure the major consumption is for cooling, followed by lighting and other equipment. As shown in the next Figure the major consumption is for cooling, followed by heating and equipment.

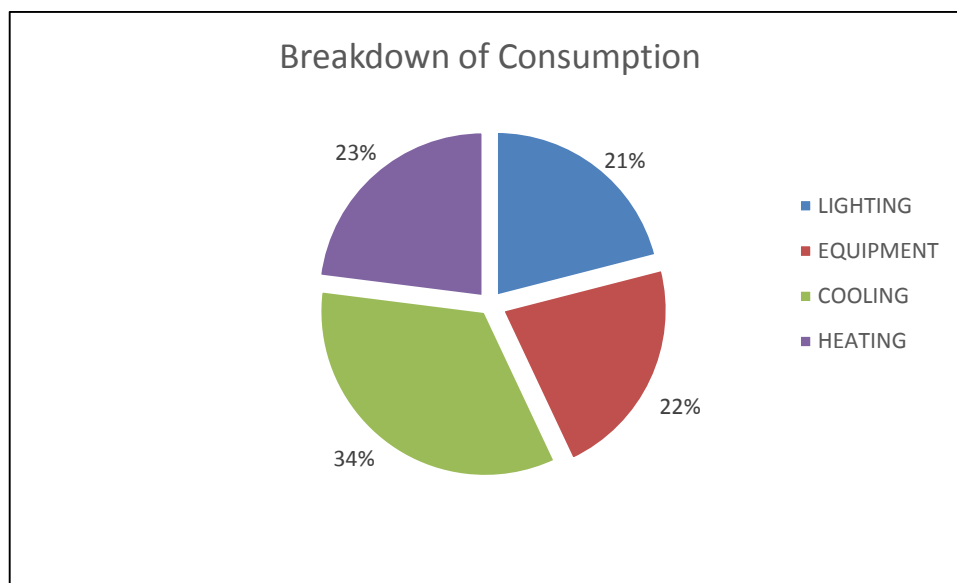


FIGURE 57: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES

Measurements were carried out in order to check the three-phase distribution and the power factor ( $\cos\phi$ ) of the building. The three-phase instant consumption of the building was measured for each floor by using a clamp-on power meter (HIOKI). These measurements show the 3-Phases are not balanced and this can cause electrical current distribution problems or overheated electrical fuses. Also the power factor  $\cos\phi$ , was below the standard value of 0.95, the lowest permitted value for public buildings. The replacement of the current T8 fluorescent lamps with LED will contribute to the improvement of the power factor.

#### 6.3.2. GAS/OIL CONSUMPTION

The building does not have any consumption from gas or oil.

#### 6.3.3. RENEWABLE ENERGY SOURCES

The building does not have any renewable energy sources.

#### 6.3.4. OTHER GENERATION

The building does not have any other source of generation.

#### 6.3.5. FINAL ENERGY CONSUMPTION AND CO<sub>2</sub> EMISSIONS

Summarising the data of the monthly electrical consumption from the Utility invoices we have the following consumptions per year given in Table 40. These tabulated figures include only the consumption relevant to the building's needs. The consumption generated by the water pumping system has been subtracted as the latter does not take part in the renovation design.

TABLE 40: ANNUAL ELECTRICITY CONSUMPTION DURING THE PERIOD 2011-2013

Year	Total Consumption (kWh)
2011	40,292
2012	35,217
2013	30,927
Average	35,478

The average annual total specific consumption of the building is 114 kWh/m<sup>2</sup>.

Table 41 presents the yearly electrical consumption of the building converted to primary energy and to CO<sub>2</sub> emissions. The values were calculated using the following conversion factors in accordance with the Greek regulation of the energy performance of buildings, KENAK:

- electricity to primary energy – 2.9 (according to Greek regulation of the energy performance of buildings KENAK)
- electricity to CO<sub>2</sub> emissions – 0.989 kg/kWh (according to Greek regulation of the energy performance of buildings KENAK)

TABLE 41: YEARLY PRIMARY ENERGY AND CO<sub>2</sub> EMISSIONS

Year	Final Energy kWh	Primary Energy kWh	CO <sub>2</sub> Emissions kg CO <sub>2</sub> /kWh
2011	<b>40,292</b>	<b>116,846</b>	<b>39,849</b>
2012	<b>35,217</b>	<b>102,129</b>	<b>34,830</b>
2013	<b>30,927</b>	<b>89,688</b>	<b>30,587</b>

## 7. RENOVATION SCHEME

### 7.1. AIM OF THE RENOVATION PLAN

The aim of the renovation design is to achieve nearly zero energy consumption in the Environmental Services Office ensuring at the same time thermal and visual comfort as well as impeccable functional conditions. In Greece, the definition of nearly zero energy building is currently under development. It is expected to be issued and enforced by the end of 2015. Consequently, the project team conforms to the targets set by CERTuS, namely, at least 70% reduction of building energy consumption and, use of renewable energy sources to cover at least 50% of the remaining energy needs for heating, cooling, lighting and hot water.

In parallel to the energy targets the renovation design has to comply with a constraint set by the technical department of the Alimos Municipality, namely, the renovation design should be implemented with the least annoyance for the employees or interference with the services provided to the citizens. Full or partial evacuation of the building is not foreseen as a possibility.

The main difficulty that was faced during the design stage is that the total consumption is relatively low because of the services and the equipment which are hosted by the environmental services office. For this reason the potential energy savings are relatively low and the corresponding operating cost savings are low too which means that the renovation plan could be not feasible. Simultaneously, the main advantage of this building is the free space around it and on the roof which can be used for installing PV system with only restriction the upper limit that Greek regulation set.

The holistic approach of the building for nearly zero energy renovation includes extra insulation to the entire envelope and new low-e and thermal break windows. Also the natural ventilation has to be improved to avoid the overheating of the building and to achieve the appropriate internal air quality. Other strategies to reduce even more the energy demand are the night ventilation and the use of available daylight. After minimizing the energy demand the next step is to install very innovative and efficient systems to cover the needs of buildings for heating, cooling, mechanical ventilation and lighting. The last step of the renovation plan is to add renewable energy systems in order to reach the minimum possible level for the total energy



demand. A simple BEMS system is foreseen to monitor the operation of the systems and control the proper operation of heating, cooling and lighting equipment.

## 7.2. ENERGY DEMAND REDUCTION

### 7.2.1. OPAQUE ENVELOPE

The building envelope is in good condition but has important thermal bridges that increase the current overall U-value of the opaque part by about 30%. This is due to the type of wall construction (insulation in – between the two brick layers) that makes the avoidance of thermal bridges difficult. Moreover, the current U-values of the external walls and roof are higher than those required by the new building regulation for energy efficiency, KENAK.

Therefore, the addition of external insulation was investigated as a means to improve the current conditions. Its impact on the year-round energy performance of the building was modelled by means of the simulation code EnergyPlus (see Ch. 7.6). For modelling purposes an insulating material with 0.032 W/mK conductivity was considered.

Three different values of thickness, namely, 5 cm, 7 cm, and 10 cm were successively studied. As can be seen in Figure 58, by applying 5 cm of external insulation there is an annual decrease of heating of 338 kWh. Any further increase of the insulation thickness does not significantly affect the energy consumption. Additionally, the installation of 10cm would require not only extra budget but extra structural works in order to be sufficiently supported.

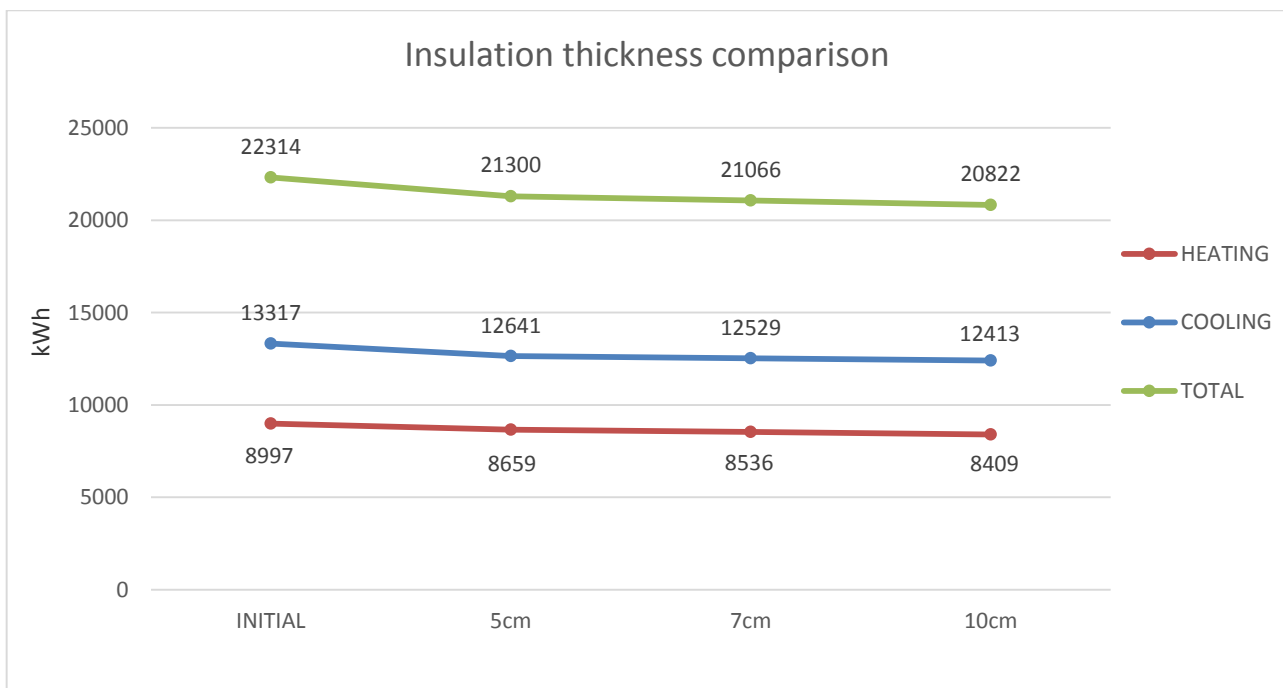


FIGURE 58: ENERGY PERFORMANCE ACCORDING TO DIFFERENT WIDTH OF INSULATION

Thus the most suitable option is the addition of 5cm external insulation of 0.032 W/mK. Any other equivalent combination is equally suitable.

Further requirements for the selection of the insulation should be:

- fulfil all the requirements of the current regulation
- provide full waterproofing
- good vapour diffusivity
- the external finish should have high impact strength

The addition of the investigated external insulation reduces the U-value of the walls from 0.587 W/m<sup>2</sup>K to 0.359 W/m<sup>2</sup>K and the U-value of roof from 0.45 W/m<sup>2</sup>K to 0.263 W/m<sup>2</sup>K.

TABLE 42: ANNUAL CONSUMPTION BEFORE AND AFTER ADD INSULATION

	Before	Retrofit	After Retrofit	
	Heating	Cooling	Heating	Cooling
Consumption (kWh)	8,997	13,317	8,659	12,641
Savings (kWh)	-	-	↓ 338	↓ 676
Savings (%)	-	-	↓ 4%	↓ 5%

### 7.2.2. OPENINGS

The existing glazing and frames with total U-value of 3.49 [W/m<sup>2</sup>K] will be replaced with low-e glazing and thermal break frame. After doing the required study about the different U-value of windows it was decided that the optimum choice of products have the following thermal properties,  $U_{\text{frame}}$  2.5 [W/m<sup>2</sup>K],  $U_{\text{glazing}}$  1.1 [W/m<sup>2</sup>K] and the window's U-value 1.8 [W/m<sup>2</sup>K]. Also they have 42% Solar Factor and 66% Light Transmission.

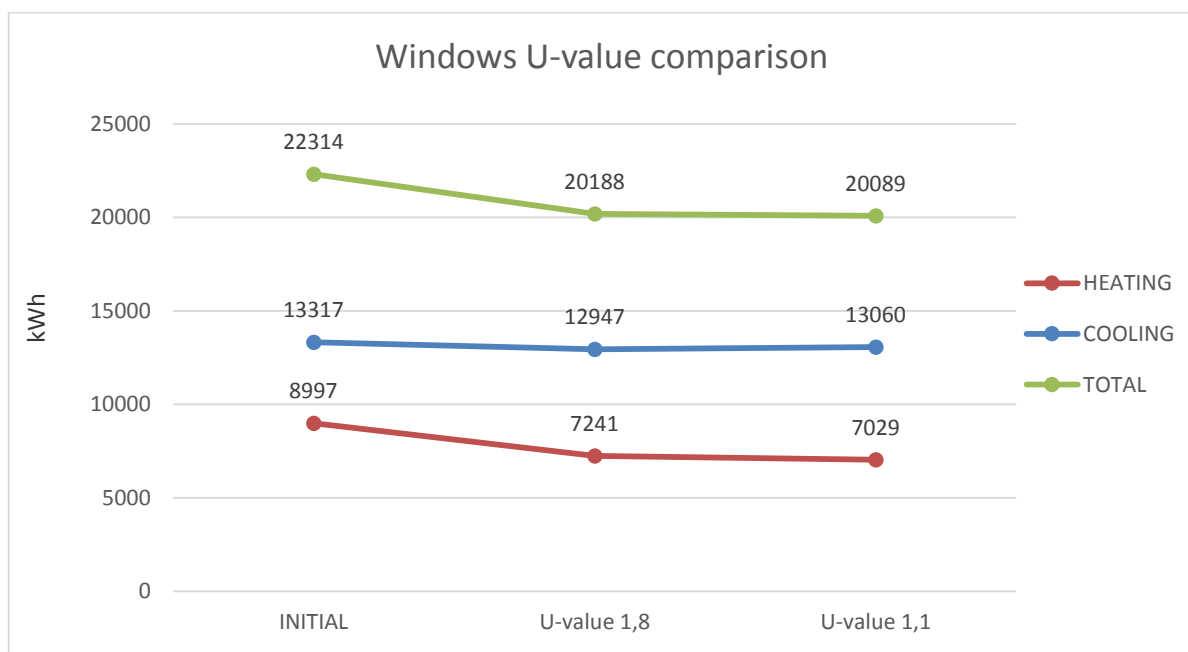


FIGURE 59: ENERGY PERFORMANCE ACCORDING TO DIFFERENT U-VALUE OF WINDOWS

As the previous figure shows the windows with lower U-value (eg 1.1 W/m<sup>2</sup>K) are not only more expensive but they do not decrease the total energy consumption significantly.

TABLE 43: ANNUAL CONSUMPTION BEFORE AND AFTER REPLACE THE WINDOWS

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
Consumption (kWh)	8,997	13,317	7,241	12,947
Savings (kWh)	-	-	↓ 1,756	↓ 370
Savings (%)	-	-	↓ 19%	↓ 3%

### 7.2.3. SHADING

In this building, external shading devices will not be installed as the roof slab which extends out of the perimeter of the building shades adequately all the openings.

### 7.2.4. NATURAL/NIGHT VENTILATION

In order to reduce further the energy demand for cooling natural/night-time ventilation is foreseen. This strategy will help also to avoid the overheating of the building and to maintain the desired indoor conditions and indoor air quality. Air vents equipped with dampers will be installed on the north and south façade of the building so to achieve cross ventilation on each floor. The study concludes that seven air inlet openings with dampers have to be integrated on the lower zone of the north façade and seven outlet openings on the upper zone of the south façade of the building.

This system will operate during night in summer (night ventilation) in order to cool the internal space by blowing fresh air inside, at a rate of 15 ACH. The inlet openings are equipped with small fans to assist air inflow in case natural ventilation does not suffice. Also, this system will operate during the day to offer the required rate of natural ventilation in periods when the outside air is cooler.

The ventilation openings will be connected with sensors of the external temperature and will operate only when the external temperature is lower than the internal. The use of these sensors ensures that the maximum saving in energy consumption for cooling will be achieved. The dampers will be insulated and airtight so to avoid any increase of heating in winter.

TABLE 44: ANNUAL CONSUMPTION BEFORE AND AFTER ADD NIGHT VENTILATION

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
Consumption (kWh)	8,997	13,317	8,997	12,651
Savings (kWh)	-	-	0	↓ 666
Savings (%)	-	-	0%	↓ 5%

## 7.3. ENERGY SYSTEMS

### 7.3.1. LIGHTING SYSTEM

As previously presented the actual lighting system is mainly constituted by fluorescent T8 linear 18 watt and 36 watt lamps with magnetic ballast. In total we have 122 fluorescent T8 lamps and lamps of different types such as circular fluorescent lamps, round and oval compact fluorescent lamps.

All lamps of the building will be replaced with new LED lamps. Two scenarios were investigated. The first scenario is to replace each lamp individually by keeping the already existing ceiling panels and the second scenario is to replace the whole panel with a new ceiling LED light panel which will give 10% more lumens per panel.

In first scenario, 141 lamps have to be replaced. Table 45 presents the already existing lamps and Table 46 shows the total power to be installed. The new installed total power is 1,870 W which is 48% of the initial power.

TABLE 45: TYPES AND QUANTITIES OF EXISTING LAMPS

Lamp Type	Quantity n	Lamp W	Total W
Fluorescent Linear T8 60 cm	92	18	1,656
Fluorescent Linear T8 120 cm	30	36	1,080
Compact Fluorescent oval lamp	7	40	280
Circular fluorescent lamp	10	35	350
High-Pressure Sodium lamp	2	250	500
		<b>Total:</b>	<b>3,866</b>

TABLE 46: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN 1<sup>ST</sup> SCENARIO

Lamp Type	Quantity n	Lamp W	Total Power W
LED Tube Glass T8 60cm	92	10	920
LED Tube Glass T8 120cm	30	18	540
LED E14	17	10	170
LED Street light	2	120	240
		<b>Total:</b>	<b>1,870</b>

In the second scenario, 38 panels have to be replaced with new ceiling LED light panels and 19 lamps will be replaced with new LED lamps. Table 47 presents the lamps to be installed and as can be noticed the total power is 2500W which is 65% of the initial one.

TABLE 47: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED IN 2<sup>ND</sup> SCENARIO

Lamp Type	Quantity n	Lamp W	Total Power W
LED Ceiling Light Panel	38	55	2,090
LED E14	17	10	170
LED Street light	2	120	240
		<b>Total:</b>	<b>2,500</b>

Additionally, it will be taken advantage of the daylight by using Lux sensors. In offices in the northeast side, the lights will be controlled by Lux sensors so as to turn off automatically when the internal lighting level has reached the pre-set desired level (e.g. 500 LUX). In total eight (8) Lux sensors will be installed. This will give an additional reduction by 16% in the total consumption.

Table 48 presents the yearly consumption for lighting in two different scenarios, as well as the percentage of achievable savings and the percentage of consumption with the Lux sensors. As can be seen, 1<sup>st</sup> scenario ensures 60% and 2<sup>nd</sup> scenario ensures 45% of energy savings.

TABLE 48: YEARLY CONSUMPTION WITH LIGHTING IN THE TWO DIFFERENT SCENARIOS

	Before Retrofit	After Retrofit Scenario 1	After Retrofit Scenario 2
Consumption (kWh)	7,846	3,766	5,100
Consumption + lux sensors (kWh)		3,164	4,284
Savings (kWh)	-	↓ 4,682	↓ 3,562
Savings (%)	-	↓ 60%	↓ 45%

After comparing the two scenarios the first one is selected because it gives adequate lighting levels and at the same time it yields 15% more energy savings. Additionally the second scenario has a much higher cost.

### 7.3.2. HVAC SYSTEM

A new HVAC system will replace the existing systems. This will be a multi-zone VRV system. The VRV system includes one external and fourteen internal units. The external unit, VRV heat pump will be placed in the open space southwest of the building. The internal units, ceiling mounted cassettes will be installed in every office and will be controlled by their individual controllers so that every office has the desired internal air temperature.

The fresh air in all offices will be ensured by openings equipped with fans and dampers and located on the outer walls, (low on north walls and high on the south). These openings will be able to close completely when are not needed. The circulation of fresh air will be used for cooling the envelope at night throughout the summer.

Renovating the old HVAC system with a new VRV system offers the ability of an autonomous operation locally in each indoor unit and, savings in operating costs because of the higher EER and COP values. The old system has COP and EER values 1.7 and 1.5 respectively while the new one has a COP of 4.05 and EER of 3.61. The increased performance ratio of the new system will ensure less use of electricity resulting thus in greater energy efficiency.

The new VRV system has small refrigerant pipes which take up less space in shafts and ceilings and the VRV Cassette dimension 62 cm x 62 cm make the installation easy and without extra need of reconstructing the fibre suspended ceiling.

In the following table are presented the technical characteristics and the units of the new HVAC system:

TABLE 49: HVAC SYSTEM - UNITS

Area	Units	Nominal Capacity (kW)		Performance Ratio		Type
		COOLING	HEATING	EER	COP	
OUTDOOR	1	33.5	37.5	3.73	4.31	VRV HEAT PUMP
OFFICES	14	2.8	3.2			VRV CASSETTE

Table 50 presents the annual consumption with the existing HVAC system for heating and cooling and the retrofit scenario. As can be seen, with the latter, energy savings of 58% can be achieved.

TABLE 50: ANNUAL CONSUMPTION BEFORE AND AFTER RETROFIT

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
Consumption (kWh)	8,997	13,317	3,779	5,593
Savings (kWh)	-	-	5,218	7,724
Savings (%)	-	-	↓ 58%	↓ 58%

The renovation of an existing HVAC system gives a great opportunity to increase the energy efficiency of the whole building and improves the internal conditions providing a comfortable environment to the users. The users will have the possibility to choose the desired room temperature through the individual room controller.

## 7.4. RENEWABLE ENERGY SOURCES

### 7.4.1. PV GENERATION

In order to ensure that 50% of the consumed energy in the building is generated by renewable energy sources, a photovoltaic system of 26.7 kWp will be installed on the building's roof. The PV panels will be placed due south with a fixed slope of 25°. The photovoltaic system will be connected to the low voltage grid via three phase power.

The electric energy generated by the photovoltaic system will be provided to the Utility according to the Greek regulation on "Net-metering". The prescribed procedure is the following: the prescribed procedure is the following. In each measurement cycle and billing, the electricity consumed by the building will be offset with the electricity generated by the photovoltaic system. In case there is excess energy this will be credited to the next billing period. At the end of the year the excess is cleared without compensation. Figure 60 shows the PV panels implemented into the roof.



FIGURE 60: PV PANELS INSTALLED IN THE ROOF

The PV system will consist of eighty four (84) Photovoltaic panels with nominal power of 318 Wp each. The connection to the low voltage grid will be done through nine (9) DC/AC inverters with rated output of 3,000 Watt each and the total rated power of the PV system is 26.7 kWp.

The production of the PV system was estimated using PVGIS, a software developed by The Joint Research Centre of the European Commission in ISPRA, Italy.

The monthly and annual solar radiation in the area based on the PVGIS database is presented in the following table.

TABLE 51: SOLAR RADIATION VALUES AT THE AREA OF ALIMOS - SOURCE: PVGIS DATABASE (KWH/ M<sup>2</sup>/MONTH) - 25°

Month	Irradiation at inclination: (kWh/m <sup>2</sup> /month) 25° deg
JANUARY	91
FEBRUARY	95
MARCH	140
APRIL	168
MAY	193
JUNE	205
JULY	210
AUGUST	201
SEPTEMBER	178
OCTOBER	135
NOVEMBER	89
DECEMBER	79
<b>YEAR</b>	<b>1,784</b>



According to PVGIS the 26.7 kW will produce **37,300 kWh** per year.

The monthly energy production and the PVGIS estimation are shown in the next figures.

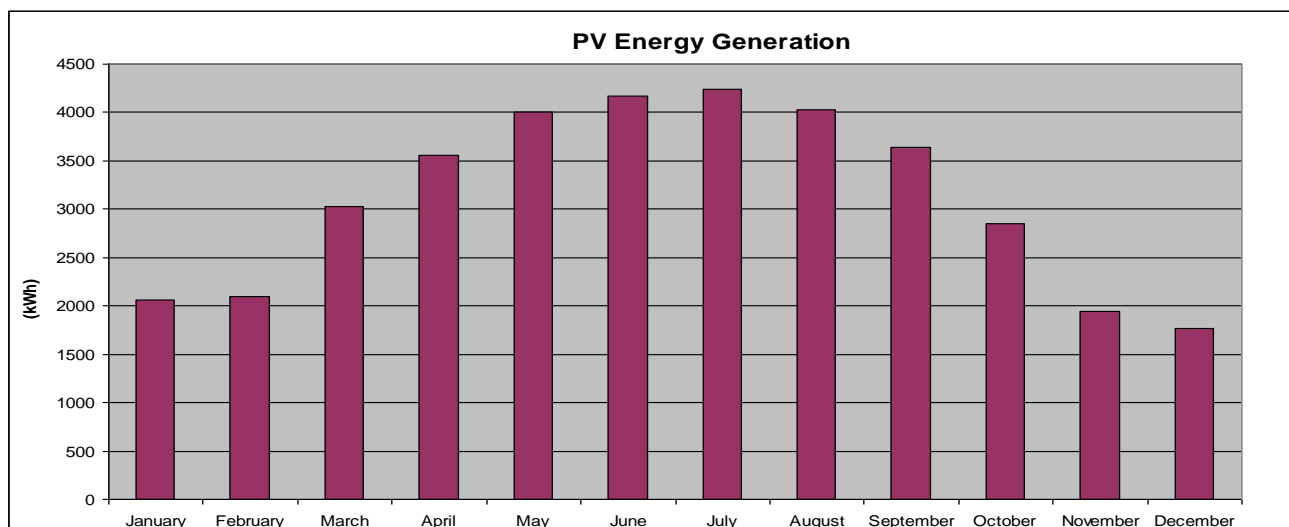


FIGURE 61: ENERGY INJECTED INTO GRID FROM THE PV SYSTEM

Additionally, a second PV system of 15 kWp may be accommodated to supply electricity to other municipal buildings if this will be permitted by the regulations (defining nZEB levels) that are currently under development. The PV panels will be mounted on a shading structure to be constructed at the north side of the parking area.



FIGURE 62: PV PANELS INSTALLED IN THE ROOF AND IN THE PARKING AREA

The monthly energy production of both PV systems is shown below.



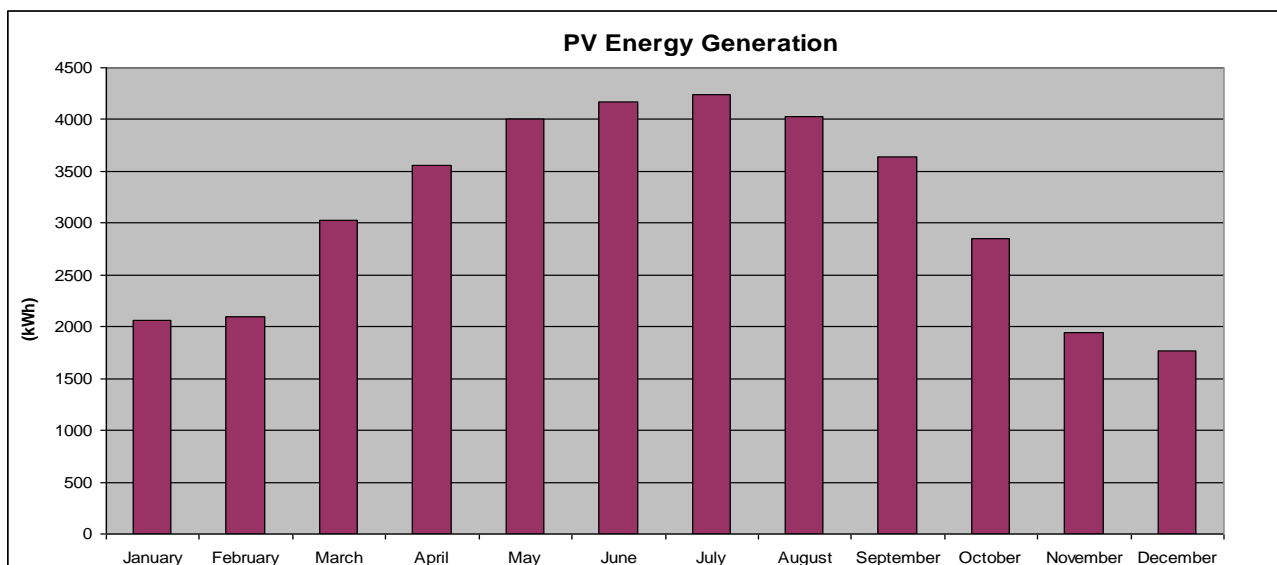


FIGURE 63: ENERGY INJECTED INTO GRID FROM THE PV SYSTEM

In total the 41.7 kWp photovoltaic system will produce an average of **58,126 kWh** per year.

#### 7.4.2. SOLAR COOLING-HEATING SYSTEM

In order to integrate more environmental friendly systems to the building, the use of a solar cooling-heating system was investigated so as to cover the building's cooling and heating demands.

The examined system consists of 40 m<sup>2</sup> high performance solar collectors, an absorption chiller with power for cooling and heating 24 kW and 80 kW respectively and a cooling tower of 58 kW.

Even though the building has the required space for this installation, it was not selected. The reason of the rejection is that this system has very low performance and covers only 30% of the annual cooling-heating load of the building. This fact, combined with the high initial cost which is estimated more than 100,000 €, makes the investment not feasible.

#### 7.4.3. SOLAR THERMAL COLLECTORS

The building's needs for hot water are negligible and so there is no renovation plan regarding the use of solar thermal collectors.

### 7.5. ENERGY MANAGEMENT SYSTEM

Maximum efficiency demands the maximum control of all building's equipment. In order to optimize the performance of the building's mechanical and electrical equipment such as, lighting, ventilation and HVAC system, an energy management system (BEMS) will be installed. The BEMS consists of one Touch Controller (LCD touch screen), power meters, electrical wiring equipment and a software. The BEMS will send and receive a total of 48 signals in digital and analogue format or pulse tones. The equipment which is connected to the BEMS is presented in table below.

TABLE 52: EQUIPMENT CONNECTED WITH BMS

Equipment	Units	Signal
VRV Heat Pump	1	digital
VRV Cassettes	14	digital
Air Dampers	7	analogue
Lux Sensors	7	analogue
CO <sub>2</sub> Sensors	1	analogue
Anemometer	1	analogue
Ambient Sensor	1	analogue
Power Meters	1	pulse tone
On/Off Switches	15	analogue

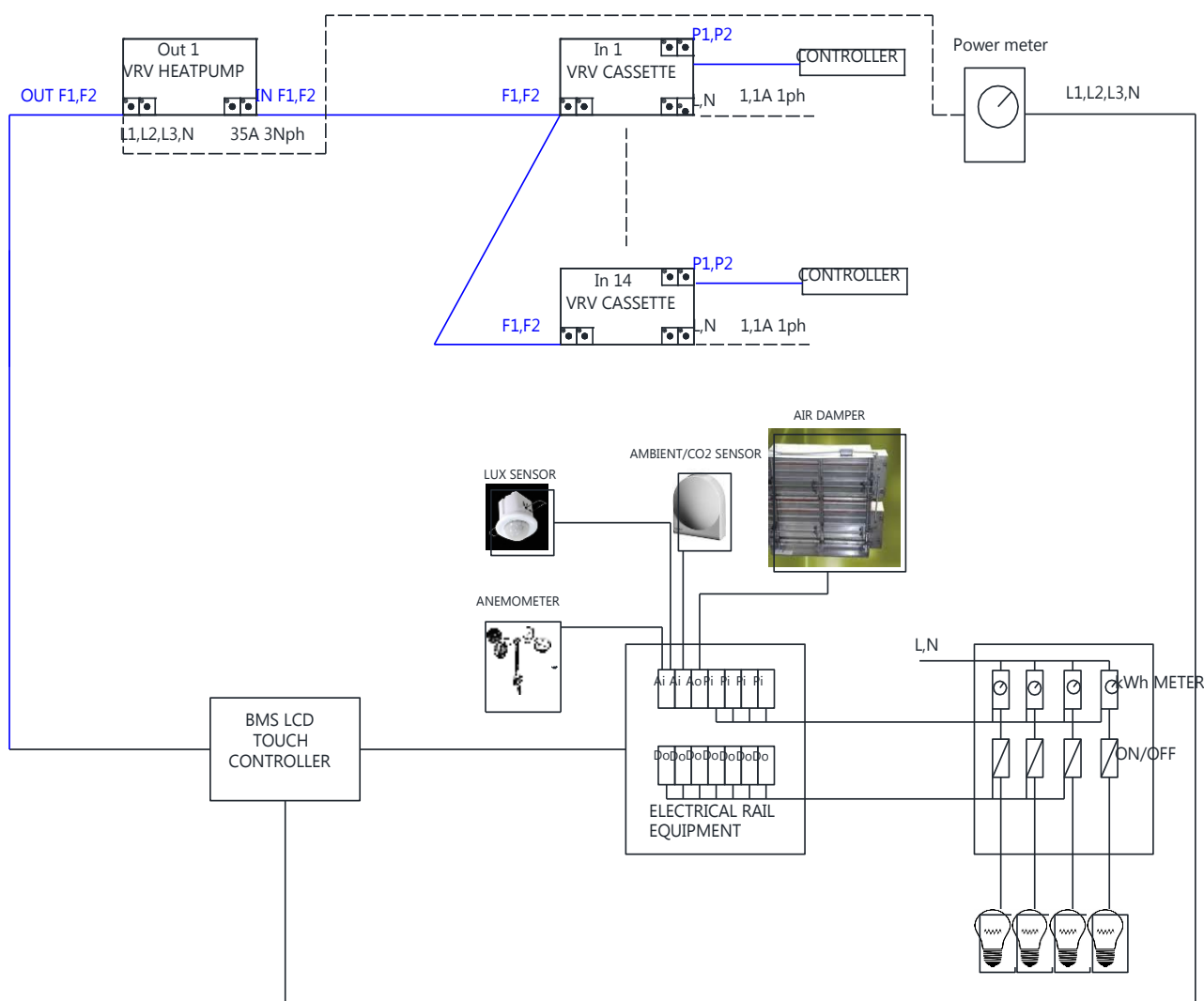
The system will perform the following advantages:

- Control each VRV, and Air Damper unit separately so as to maintain in every office the desired internal air temperature stable
- Control each Lux sensor set point so as to take advantage of the natural lighting ideally
- Daily and weekly schedule programming on/off of each VRV cassette and lighting zone in order to avoid excess use of them
- Record and store the energy consumption of each VRV cassette separately so as to detect the energy intensive units
- A software with smart power management tools doing energy saving scenarios based on the outdoor temperature
- Automatically alert/Error via email in case of system failure in order to prevent excess energy consumption or a permanent damage on the systems
- Ventilation control depending on the indoor CO<sub>2</sub> levels so as to maintain the indoor air quality

The BMS will control, monitor and record data such as air temperatures, hours of operation and power consumption, of each VRV cassette separately. Also it will control, monitor and record the lighting energy consumption of each floor separately and the operation of each Lux sensor.

In all windows and doors will be placed an on/off touch connected with each VRV cassette operation. If a window is open, it will stop the operation of the corresponding VRV. The opening and closing of the openings will be recorded by the BEMS.

The BEMS layout is presented below.



**FIGURE 64: BMS LAYOUT**

Table 53 presents the achievable savings, with the BEMS integration. The use of the BEMS ensures the standard internal conditions such as air temperature and lighting levels and prevents the excess use of energy.

**TABLE 53: ENERGY CONSUMPTION SAVINGS WITH THE USE OF BEMS**

	Before Retrofit			After Retrofit		
	Heating	Cooling	Lighting	Heating	Cooling	Lighting
<b>Consumption (kWh)</b>	8,997	13,317	7,846	5,758	9,056	6,591
<b>Savings (kWh)</b>	-	-	-	3,239	4,261	1,255
<b>Savings (%)</b>	-	-	-	↓ 36%	↓ 32%	↓ 16%

In total, the energy savings are up to 29% and the total energy conservation is 8,755 kWh/year. Other advantages are that building acquires a sophisticated method to monitor and control its energy needs and this fact will increase its energy efficiency generally. Also, the BEMS automatically can detect the energy intensive units and make energy saving scenarios with no need of human intervention. Finally, savings in

money is also achievable due to the lower cost of the maintenance of the VRV systems as BEMS displays the units with the lower refrigerant and prevents permanent damages on the HVAC.

## 7.6. TOTAL IMPACT OF THE RENOVATION SCHEME

### 7.6.1. ENERGY PERFORMANCE

The energy analysis of the building was carried out using the EnergyPlus v7.2 building simulation code. The building was described in due detail following the architectural drawings and results from the energy audit regarding lighting, equipment, and, building and systems operation profile. The parameters used for the simulations are shown in ANNEX B-3 and B-4.

The weather data used in EnergyPlus for the simulation are taken from a meteorological station which is located at Ellinikon nearby Alimos {N 37° 54'} {E 23° 43'}, 15m above sea level. The comparison between the weather data from HNMS (Hellenic National Meteorological Service) and those that EnergyPlus uses are in good agreement.

Two scenarios were simulated. In the first scenario the thermostat set points are according to the Greek regulations, namely, 20 °C for heating and 26 °C for cooling. The second scenario is more realistic regarding the building's operational profile and the thermostats' set-points are set at 22 °C for heating and 24 °C for cooling. These values result from the site inspection.

The consumptions for the first scenario, second scenario and the actual one from Utility invoices are displayed below. It is noted that the heating and cooling consumptions are calculated based on the cooling and heating demands resulted from EnergyPlus and considering that COP and EER of the building's air conditioning systems are equal to 1.7 and 1.5 respectively. This is in line with the national regulation, KENAK, for old air-conditioning systems that are not properly maintained.

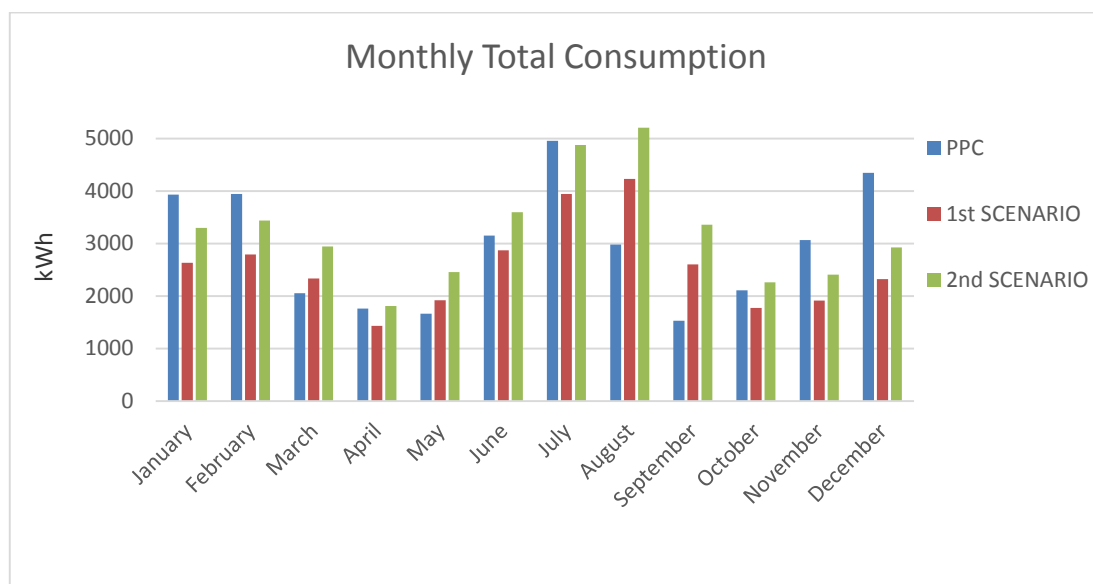


FIGURE 65: COMPARING ENERGYPLUS RESULTS WITH PPC INVOICES MONTHLY CONSUMPTIONS

\* The water pump consumption is excluded from the monthly Utility invoices

TABLE 54: ANNUAL TOTAL ELECTRICITY CONSUMPTION

Utility (kWh)	1 <sup>st</sup> Scenario (kWh)	2 <sup>nd</sup> Scenario (kWh)
35,479	30,733	38,556

The actual consumption which results from the Utility's bills is between 1<sup>st</sup> and 2<sup>nd</sup> scenario (when we exclude the water pump)<sup>3</sup>. The difference between the realistic and the actual consumption is around 8% and this is negligible so all the interventions will be applied on the second scenario's model. The reason for this slight difference could be the fact that there is not a central HVAC system in the building having standard set points as there is in the EnergyPlus model.

The following table shows how each intervention affects the energy consumption of the building. The changes are displayed separately for heating, cooling, lighting and total in order each intervention to be evaluated in a very detailed way.

The calculations are based on the optimum choices regarding all the interventions as they presented in paragraphs 3.2 to 3.5. The selected renovation plan is the following:

- Add external insulation of 5cm thickness and conductivity  $\lambda$  (k) equal to 0.032 W/mK
- Replacement of the windows with total U-value 1.8 W/m<sup>2</sup>K, Solar Factor of 42% and Light Transmission 66%
- Replacement of all lamps with LEDs
- Replacement of the installed A/C with VRV (Ceiling-Mounted Cassette) and VHR (ventilation with 40% heat recovery)
- Add night ventilation of 15 ACH
- Add BEMS for the whole building in order to control, monitor and record the energy consumption
- Install PVs on the roof 26.7 kWp

<sup>3</sup> The HDD and CDD which are calculated for the weather station of Ellinikon (nearby to Alimos) under the Greek regulation diverge from those which are used from EnergyPlus only by 6% and 3% respectively. More specific the HDD according to Greek regulation are 944 and to EnergyPlus are 1,010, and the CDD according to Greek regulation are 1,111 and to EnergyPlus are 1,079. The normalization of the actual consumption of the three years increases the average value by 4.5%, from 148,613 kWh to 155,449 kWh. Due to the insignificant change, the real consumption was compared directly with the calculated one without a degree day correction.

TABLE 55: ENERGY SAVINGS FROM EACH INTERVENTION

		HEATING	COOLING	LIGHTING	ELECTRICITY
		ENERGY SAVINGS [%]	ENERGY SAVINGS [%]	ENERGY SAVINGS [%]	POWER [kWh/year]
BUILDING ENVELOPE	<b>External Insulation</b> U-value= 0.032 W/mK d= 5 cm	4 ↓	5 ↓	-	
	<b>Windows</b> Low-e, U-value= 1.8 W/mK	19 ↓	3 ↓	-	
HVAC	<b>VRV system</b> COP= 4.05 EER= 3.61	58 ↓	58 ↓	-	
	<b>BEMS</b> standard setpoints	36 ↓	32 ↓	-	
	<b>Night Ventilation</b>	-	5 ↓	-	
LIGHTING	<b>LED</b>	-	-	52 ↓	
	<b>BEMS</b> control for daylighting use	-	-	16 ↓	
RES	<b>PV</b> on the roof 26.7 kWp				37,300

The impact that each intervention has on other parameters like internal conditions, users comfort, etc has to be evaluated too.

The following table shows the accumulative effect on the energy consumption of the building during the implementation of the renovation plan. The changes are displayed separately for heating, cooling, lighting and total in order the renovation plan to be evaluated in different phases.

TABLE 56: ACCUMULATIVE ENERGY SAVINGS FROM THE INTERVENTIONS

ENERGY	Heating		Cooling		Lighting		Total	
	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]
INITIAL	8,997	-	13,317	-	7,846	-	30,160	-
INSUL	8,659	-4%	12,641	-5%	7,846	0%	29,146	-3%
WIND-INSUL	6,353	-27%	12,201	-3%	7,846	0%	26,400	-9%
INSUL-WIND-NV	6,353	0%	11,419	-6%	7,846	0%	25,618	-3%
INSUL-WIND-NV-VRV	2,667	-58%	4,745	-58%	7,846	0%	15,258	-40%
INSUL-WIND-NV-VRV-LIGHTING	2,667	0%	4,745	0%	3,766	-52%	11,178	-27%
INSUL-WIND-NV-VRV-LIGHTING-BEMS	1,620	-39%	3,134	-34%	3,164	-16%	7,917	-29%

INSUL: extrenal insulation
WIND: windows
NV: night ventilation
VRV: new system
LIGHTING: led
BEMS: VRV and Lighting control

These data shows how the different interventions interact with each other and with the energy consumption from different uses. This information is very important because the final condition of the building is not just the sum of all different savings, and so, it is not easy to be estimated without the appropriate simulations.

#### 7.6.2. ENVIRONMENTAL PERFORMANCE

The following table is shown the initial and the final consumption after implementing all the proposed interventions in the building.

TABLE 57: ENERGY CONSUMPTION BEFORE AND AFTER RENOVATION PLAN

ENERGY	Heating		Cooling		Lighting		Total	
	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]
INITIAL	8,997	-	13,317	-	7,846	-	30,160	-
FINAL	1,620	-82%	3,134	-76%	3,164	-60%	7,917	-74%

As it was expected the energy consumption for cooling is higher than the corresponding in heating and this is because of the use of the building (offices). Additionally, it is important to mention that energy

consumption for lighting is large part of the total one. The energy consumption after the renovation is finally reduced by 7,377 kWh for heating, 10,183 kWh for cooling, 4,682 kWh for lighting and 22,243 kWh in total.

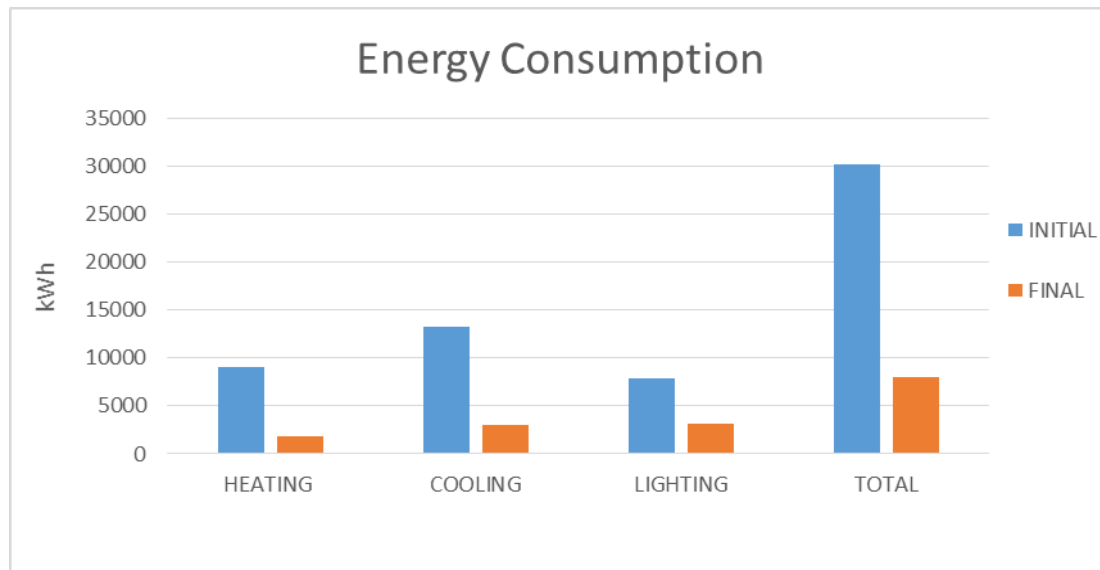


FIGURE 66: COMPARISON OF ENERGY CONSUMPTION FOR EACH USE

The results were also assessed in terms of primary energy and CO<sub>2</sub> emissions considering the following conversion factors which are taken by the Greek regulation for the energy performance of buildings:

- electricity to primary energy – 2.9 (according to Greek regulation of the energy performance of buildings KENAK)
- electricity to CO<sub>2</sub> emissions – 0.989 kg/kWh (according to Greek regulation of the energy performance of buildings KENAK)

TABLE 58: PRIMARY ENERGY CONSUMPTION AND CO<sub>2</sub> EMISSIONS BEFORE AND AFTER RENOVATION PLAN

	Heating		Cooling		Lighting		Total	
	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]
<b>INITIAL (primary energy)</b>	26,091	-	38,620	-	22,753	-	87,465	-
<b>FINAL (primary energy)</b>	4,697	-82%	9,088	-76%	9,174	-60%	22,959	-74%
<b>INITIAL (CO<sub>2</sub> emissions) [kg CO<sub>2</sub>]</b>	8,898	-	13,171	-	7,760	-	29,829	-
<b>FINAL (CO<sub>2</sub> emissions) [kg CO<sub>2</sub>]</b>	1,602	-82%	3,099	-76%	3,129	-60%	7,830	-74%



The previous table shows the comparison regarding consumption and the savings in primary energy and CO<sub>2</sub> emissions before and after the renovation. The achieved savings are 74% in total primary energy and CO<sub>2</sub> emissions which are 64,506 kWh and 22 tons of CO<sub>2</sub> emissions respectively.

Also, the proposed PVs system produces 37,300 kWh/year which means that 100% of the total annual electricity demand (for heating, cooling and lighting) will be covered by renewable energy sources and the surplus of produced energy will be used to other uses, such as the equipment of the building (PC, printers, etc) and the water pump (see 6.2.3).

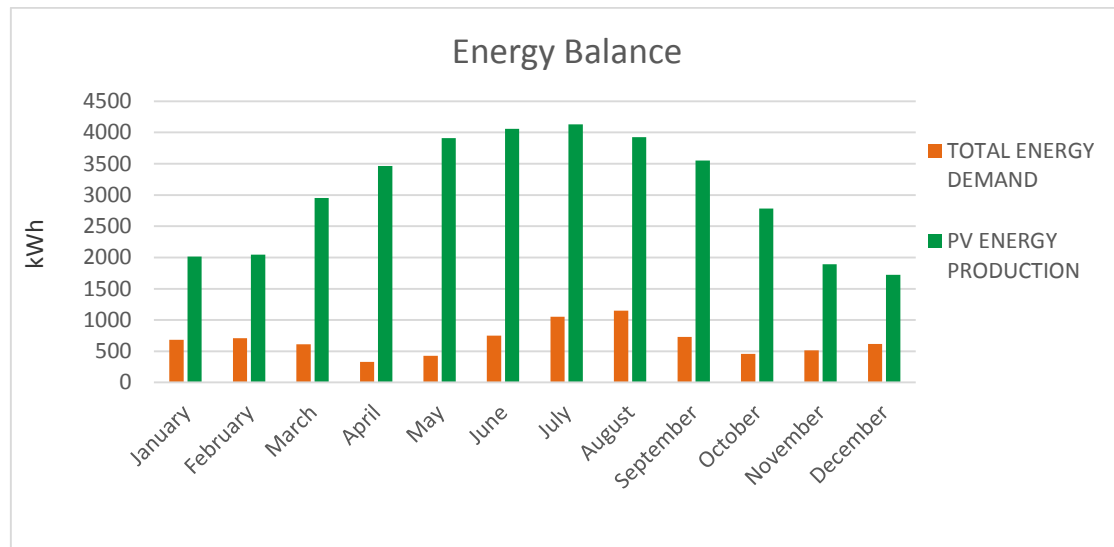


FIGURE 67: ENERGY INJECTED INTO GRID FROM THE PV SYSTEM

As it is shown on the graph above, the energy production of the PV system throughout the year exceeds the corresponding energy demand.

Finally, after subtracting the final demand of electricity from the energy which is produced by the PVs system annually, there is a surplus of 29,383 kWh which will be distributed to other uses as it was mentioned above. The energy consumption from the equipment and water pump is 30,296 kWh annually, which means that the whole amount of the surplus energy will be consumed by these uses. This leads to supplementary savings of the CO<sub>2</sub> emissions as well by 29.06 tons and in total by 51.06 tons.

## FINAL RENOVATION

<b>Building Envelope</b>	<ul style="list-style-type: none"> <li>External insulation</li> <li>Low-e glazing windows</li> <li>Solar gains circulation</li> <li>Natural and Night Ventilation</li> </ul>	Primary Energy Consumption for Heating	15.10 kWh/m <sup>2</sup>
		Primary Energy Consumption for Cooling	29.22 kWh/m <sup>2</sup>
		Primary Energy Consumption for Lighting	29.50 kWh/m <sup>2</sup>
		Energy production from PV	119.9 kWh/m <sup>2</sup>
<b>Energy Systems</b>	<ul style="list-style-type: none"> <li>VRV System</li> <li>LED lighting with Lux sensors</li> <li>BEMS</li> </ul>	Primary Energy Savings from Interventions	74%
		Energy Savings with PV	100%
		Total Primary Energy Savings	100%
<b>RES</b>	<ul style="list-style-type: none"> <li>PV system</li> </ul>		

## 8. ECONOMIC EVALUATION OF THE PROPOSED RENOVATION SCHEME

### 8.1. ASSUMPTIONS AND COST FIGURES

The cost of the interventions is estimated based on current market prices of the equipment and the installation works. Special meetings with suppliers were held to present the project and request offers for the preliminary renovation design. Offers were collected and assessed.

For each intervention, the cost has been calculated as the sum of costs for equipment, installation, operation and maintenance. These values have been organised in an Excel file prepared by Sinloc, a partner of the CERTuS consortium /4/. ANNEX B-6, gives the cost information.

The economic appraisal of the renovation design was performed by means of a tool produced by ETVA VIPE, also a partner of the consortium. A detailed description of the tool is presented in /4/. The appraisal can be performed for each intervention separately and, for the whole design. The tool also allows to examine various financing schemes ranging from single financing source to multiple, combining bank loans, ESCOs, subsidies, municipality's own equity.

As output, it gives the NPV, IRR and payback time for each financing source and for the total investment. Also the cash flow over the examined period is given.

The data used for the calculations are tabulated below (Table 59).

TABLE 59: DATA FOR THE ECONOMIC EVALUATION OF INTERVENTIONS

PARAMETER	INTERVENTION						
	Insulation	Windows	VRV	N. Vent.	Lighting	BEMS	PV
Cost of intervention (€)	26,700	12,300	21,550	3,875	4,041	10,824	45,977
O&M cost (€)(*)	0	0	9,801	3,267	1,117	8,168	8,168
Extraordinary maintenance cost (€) (*)	0	404	3,984	1,352	0	3,134	5,976
Cost of energy before( €)	5,429	5,429	5,429	5,429	5,429	5,429	5,429
Cost of energy After (€)	5,246	5,049	3,099	5,309	4,694	3,853	0
Change of energy cost over examined period (**)	1%	1%	1%	1%	1%	1%	1%
Equipment efficiency drop over examined period	0%	0%	0%	0%	20%	20%	0%
Interest rate	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
Discount rate	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%
Average inflation rate over examined period	2%	2%	2%	2%	2%	2%	2%

(\*) This is the cost over the lifetime of the intervention that is taken equal to 25 years for all except for the lighting that is 10 years.

(\*\*) The examined period is 25 years for all interventions except of lighting which is 10 years.

## 8.2. RESULTS

The Table below (Table 60), gives the payback time, NPV and IRR calculated for each intervention separately and for the complete design (all interventions).

TABLE 60: ECONOMIC EVALUATION OF INTERVENTIONS

	Insulation	Windows	VRV	N. Vent.	Lighting	BEMS	PV	ALL Interventions
Payback period (years)	23	23	10	23	6	8	7	13
NPV	-22,655	-4,299	9,731	-3,766	1,339	10,219	54,840	21,215
IRR	-5.6%	1.05%	7.71%	-42.35%	9.82%	11.02%	13.11%	5.26%

The following figure compares the payback period of each intervention as a separate investment and the combination of all the interventions.

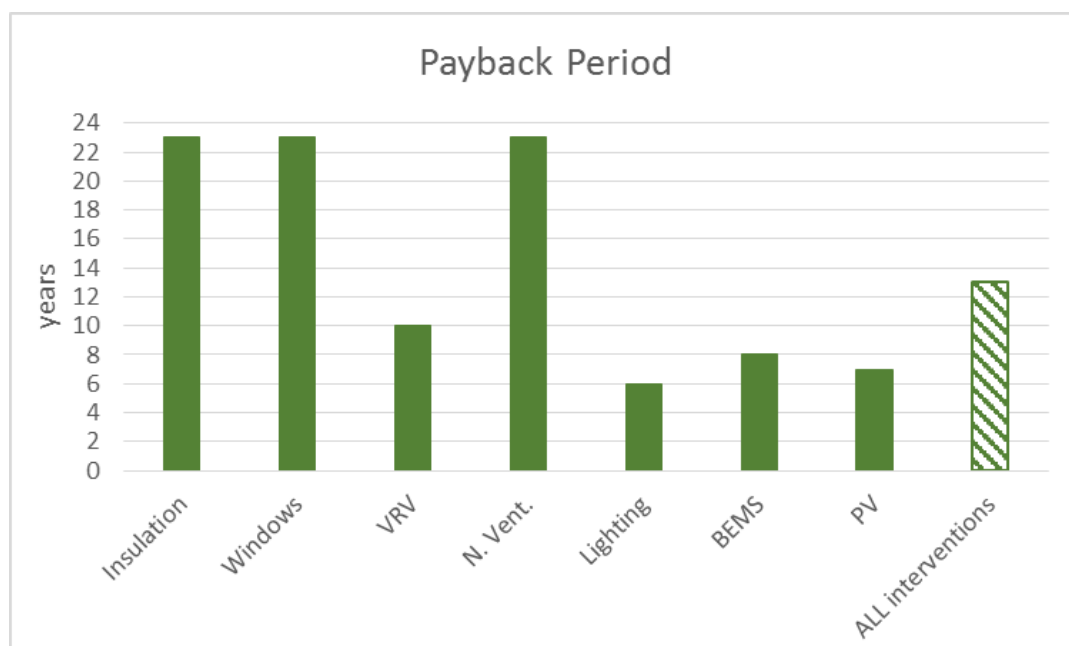


FIGURE 68: PAYBACK PERIOD FOR EACH INTERVENTION

As can be seen from the figure above if all interventions are applied they have a payback time of 13 years. It was mentioned before that the surplus energy produced from PV will be consumed by other uses and this fact affects the economic evaluation of the project too. It is assumed that the owner of the building (Municipality) will have revenues from the distribution of the extra energy and for this reason the payback period is relatively low. In reality Municipality will not sell this energy but it will save money by reducing the total cost for the building's electricity consumption. The same assumption was done in order to calculate the IRR and the NPV of the project (Figure 69, Figure 70).

Also, the interventions relevant to the envelope have lengthier payback times and so they increase the overall payback time. Although these envelope interventions have side benefits such as the prolonged lifetime of the building and the increase of asset value, the current economic appraisal focuses strictly on the annual balance of costs and savings. Thus at the period of 25 years (the common expected life span for building interventions) the net present value of the building envelope interventions is negative. This means that unless there is a suitable subsidy these interventions are not currently financially attractive. However, in the future this situation may change if the building needs or the market conditions change.

The economic appraisal of three alternative scenarios was carried out without the building envelope improvement. The first one excludes only the external insulation, the second one only the replacement of the glazing and the third one excludes both interventions. The comparison of the scenarios with the initial renovation scheme is displayed in the following table.

TABLE 61: COMPARISON OF ALTERNATIVE RENOVATION SCENARIOS

	Heating [kWh]	Cooling [kWh]	Total [kWh]	Percentage Of Energy Increase [%]
<b>Complete Renovation Scheme</b>	1,620	3,134	4,754	-
<b>Scenario 1</b> (without external insulation)	1,832	3,279	5,111	7%
<b>Scenario 2</b> (without glazing replacement)	2,218	3,240	5,458	13%
<b>Scenario 3</b> (without external insulation and glazing replacement)	2,304	3,415	5,719	17%

Table 61 shows that the increase of the energy consumption in the three alternative scenarios is not significant.

The economic evaluation of these alternative scenarios is shown in Figure 69 and Figure 70.

As can be seen, the high cost of the external insulation and windows replacement combined with the low increase in energy needs make scenario 3 the most feasible one.

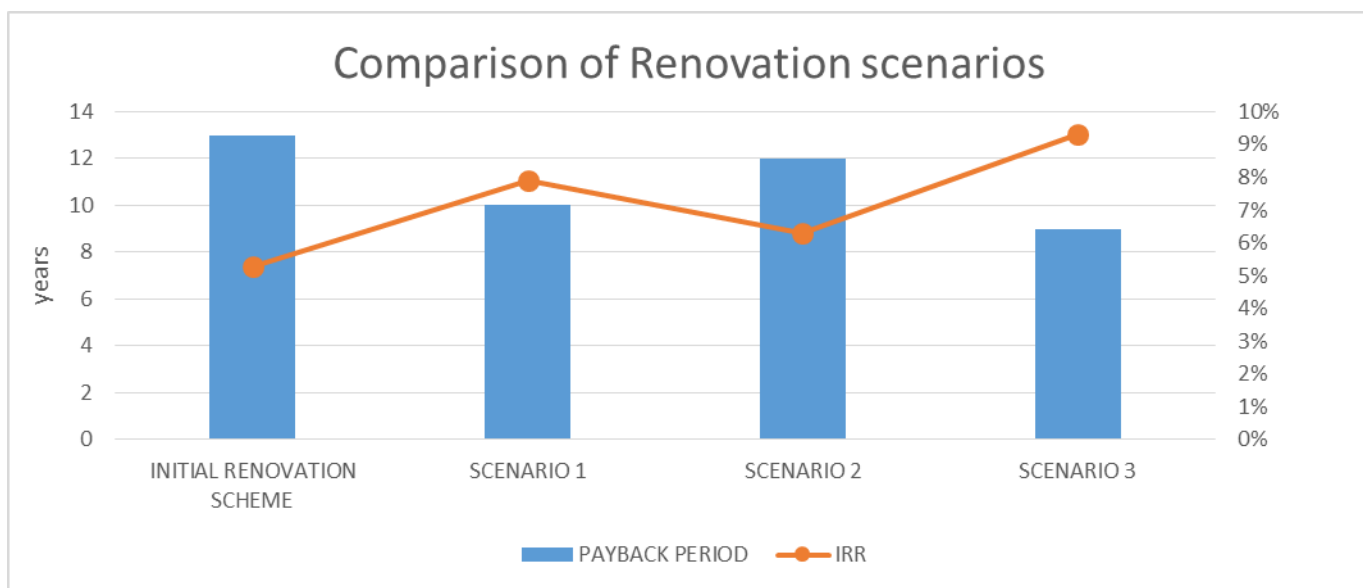


FIGURE 69: PAYBACK PERIOD AND IRR FOR ALL RENOVATION SCENARIOS

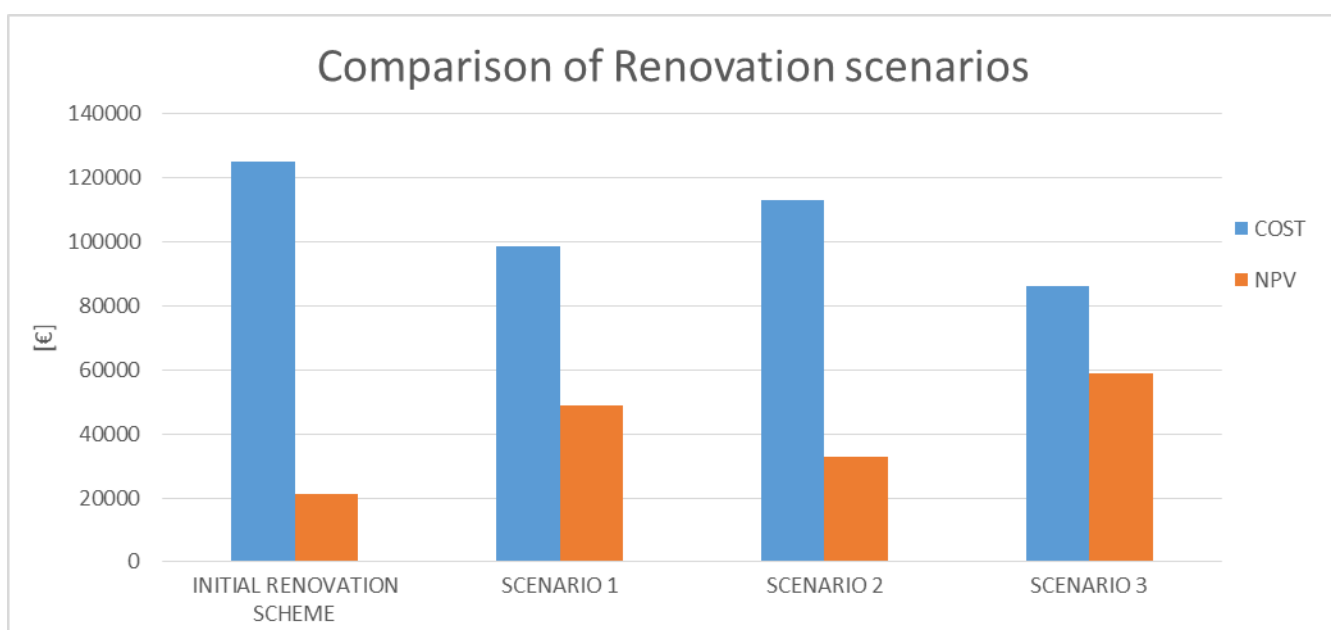


FIGURE 70: COST AND NPV FOR ALL RENOVATION SCENARIOS

The following Table (Table 62), summarises the results of the 4 scenarios.

TABLE 62: COMPARISON OF ALTERNATIVE RENOVATION SCENARIOS

Scenario	Energy Savings (%)	Res Contribution (%)	Surplus Energy From Pv (kWh)	Cost (€)	Payback Period (years)
<b>Complete Renovation Design</b>	74.0	100	29,383	125,229	13
<b>Scenario 1</b> (without external insulation)	72.5	100	29,026	98,529	10
<b>Scenario 2</b> (without glazing replacement)	71.5	100	28,678	112,929	12
<b>Scenario 3</b> (without external insulation and glazing replacement)	70.5	100	28,417	86,229	9

Even with scenario 3, the energy consumption for heating, cooling and lighting is reduced by 70.5% and so, the renovation energy target requiring reduction over 70% is achieved. At the same scenario 3, the RES contribution is 100% of the remaining energy needs and there is a surplus of produced energy 28,417 kWh.

Therefore, if the building envelope improvement cannot be funded under the current conditions, they can be excluded from the renovation plan. Probably they can be implemented at a later time or when economic conditions are more favourable.



## C. MUNICIPAL LIBRARY BUILDING

### 9. BUILDING GENERAL DESCRIPTION

#### 9.1. LOCATION

The Municipal Library building was constructed in 1984. It comprises five floors and a basement. The Municipality rents the first three storeys and the basement and houses the Municipal Library, offices, school activities and dancing courses. The rest of the building is residential. Figure 71 depicts the front façade of the building.



FIGURE 71: ALIMOS MUNICIPAL LIBRARY - MAIN FAÇADE OF THE BUILDING (SOUTHEAST SIDE)

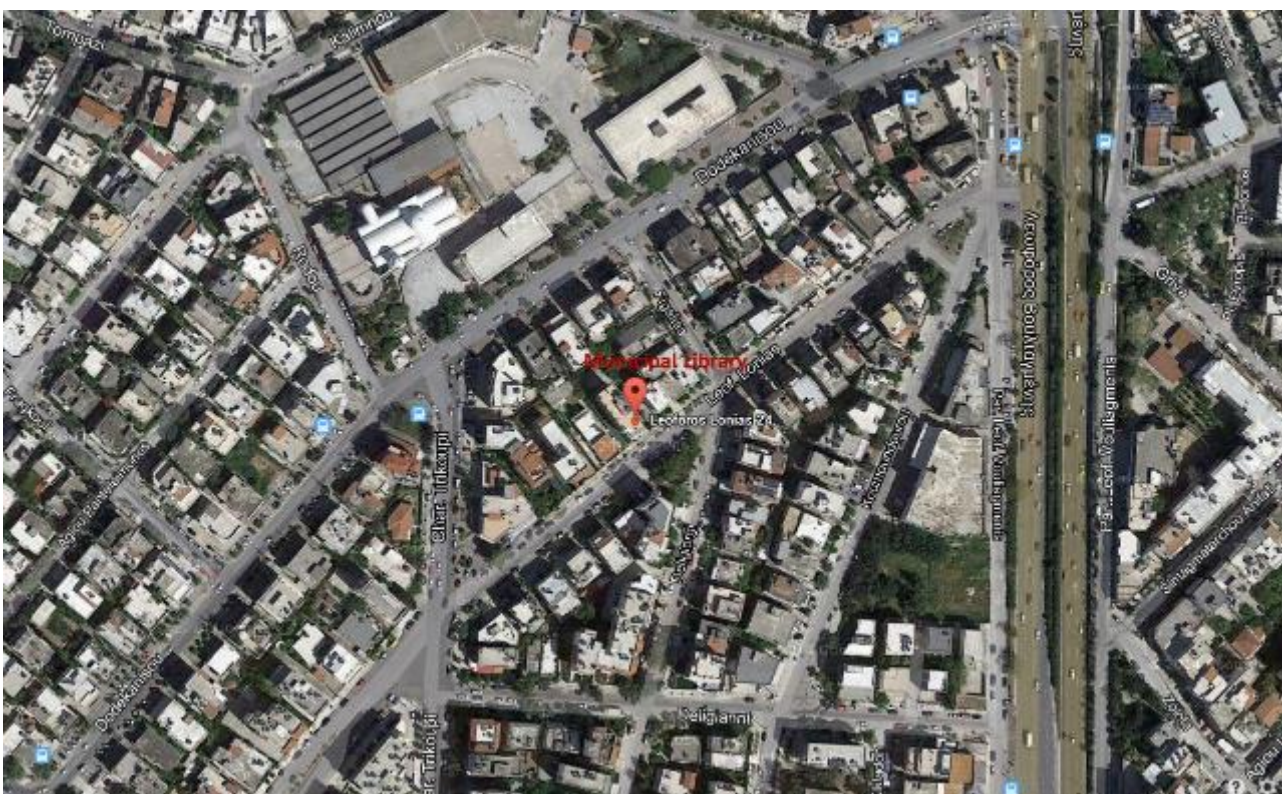
The coordinates of the building are shown in Table 63. Figure 72 and Figure 73 present the location in the map and Google Earth view.

TABLE 63: LOCATION DATA OF THE BUILDING

<b>Address</b>	Ionias 24, 174 56 Alimos, Greece
<b>Coordinates</b>	37° 55' 33.60'', 23° 44' 32.40''



**FIGURE 72: MUNICIPAL LIBRARY (MAP)**



**FIGURE 73: MUNICIPAL LIBRARY LOCATION**

## 9.2. SHAPE AND ORIENTATION

The shape of the building is elongated along the N-S axis. The orientation of the whole complex deviates 53° from south due west. Table 64, gives the orientation of the façades relative to North, considering N at 0°.

TABLE 64: ORIENTATION OF THE BUILDING

Orientation	Angle "c"
NE	53°
SE	143°
SW	233°
NW	323°

The following figures presents the plan view of the ground floor, first & second floor as well as the cross section of the building. See ANNEX C-1 for the rest drawings of the building.

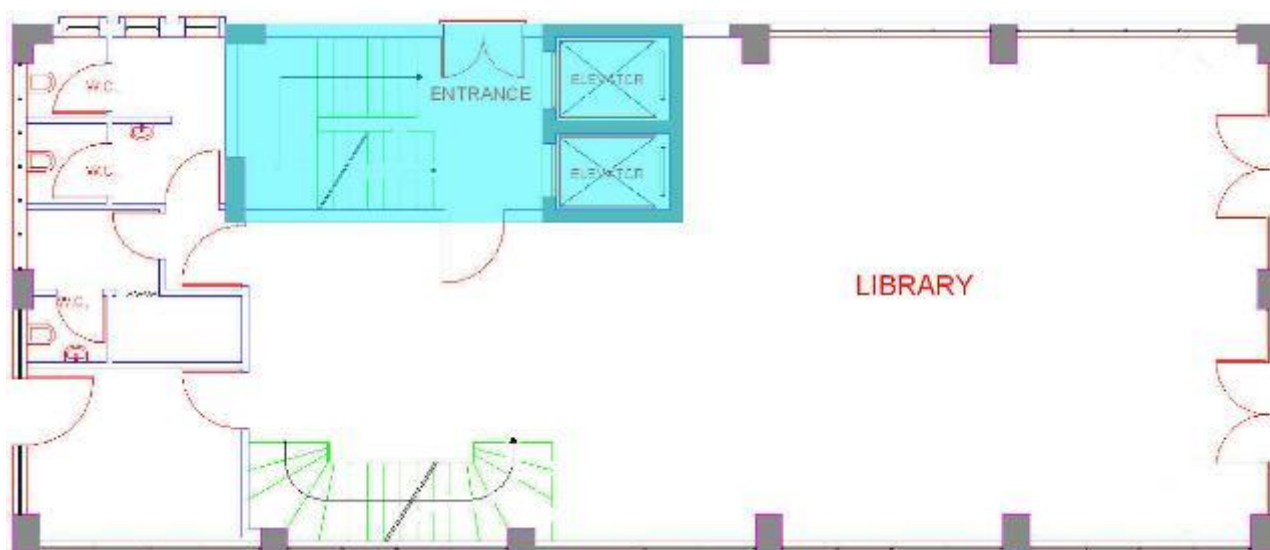


FIGURE 74: GROUND FLOOR



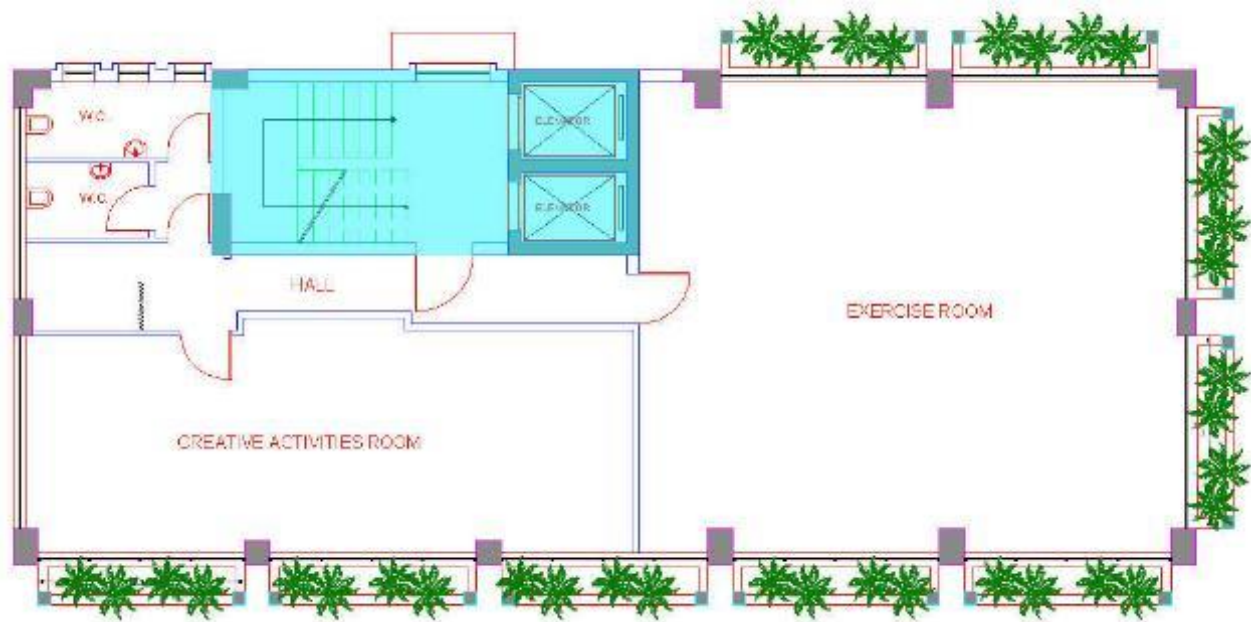


FIGURE 75: FIRST & SECOND FLOOR

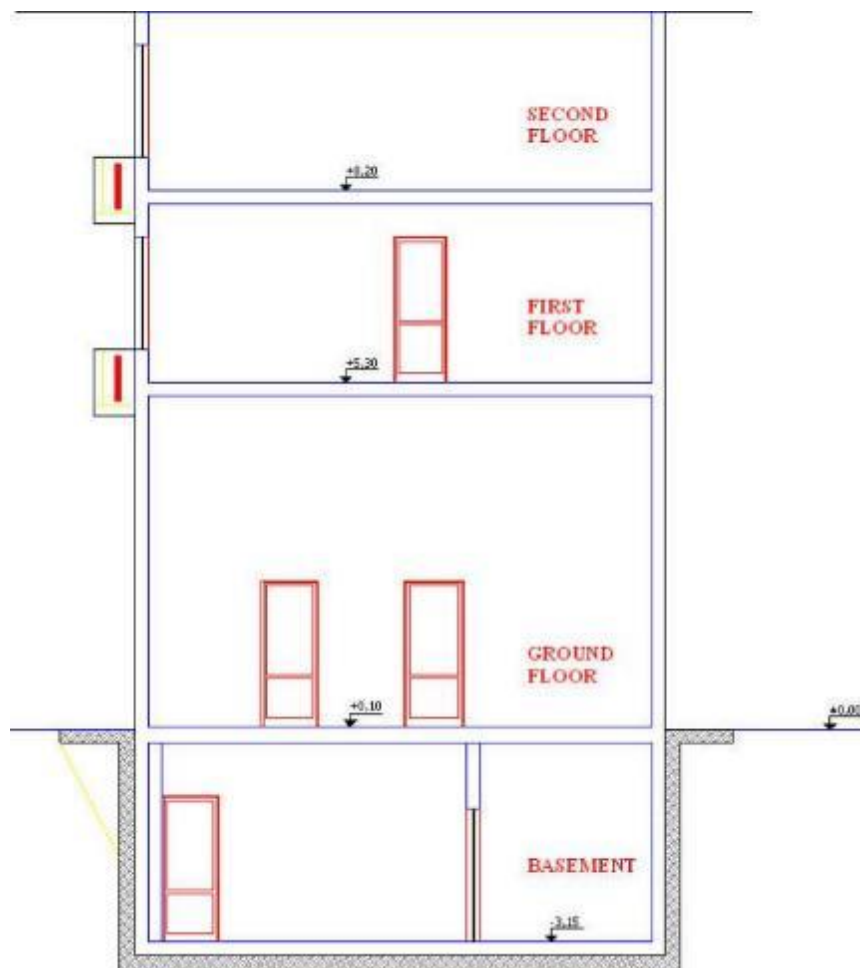


FIGURE 76: CROSS SECTION

Figure 77 shows the orientation of the building facades, the main façade and the entrance of the building is in the southeast side.



FIGURE 77: MUNICIPAL LIBRARY – ORIENTATION OF THE BUILDING FACADES

### 9.3. AREA AND VOLUME

The surface area and volume of the building are 611 m<sup>2</sup> and 2,185 m<sup>3</sup> respectively. The total treated area is 507 m<sup>2</sup> with a corresponding volume of 1,821 m<sup>3</sup>. The Table 65 below gives the surface area and volume per floor and use. The untreated areas are highlighted with gray colour.

TABLE 65: MUNICIPAL LIBRARY - SURFACE AREA AND VOLUME

Surface areas in m <sup>2</sup>					
	Library	Offices	Stairwells	Warehouse	Children's activity area
<b>Basement</b>	-	-	5.5	36.1	111.2
<b>Ground floor</b>	132	-	20.8	-	-
<b>First floor</b>	-	-	20.8	-	132
<b>Second floor</b>	-	132	20.8	-	-

## 9.4. CURRENT USE

The building comprises the following areas:

- Ground floor: it houses the Library.
- First floor: the interior is arranged as area for gymnastics and school activities. Kids every day are visiting the place for creative activities such as reading, painting, dancing etc.
- Second floor: it houses offices and a meeting room.
- Basement: a second area for gymnastics is located in the southeast side of the basement. The northwest side is used as a warehouse.

The building operates on the weekdays with the following schedule:

- Offices - 7:00 – 15:00 all year round;
- All other activities - 7:00 – 15:00 & 17:00 – 20:00

During the summer (2 months), Christmas and spring holidays (2 weeks each) the areas housing the citizens' activities remain close in the afternoon.

The occupation profile of each area is as follows:

TABLE 66: OCCUPATION PROFILE

Zone	Floor	Number of Employees	Number of Visitors/day	Hours/day of work	Hours/day of visit
1	Ground	2	10	8	0,5
2	1st	1	60	8	1
3	2nd	10	-	8	-
4	Basement	-	90	-	0.5



FIGURE 78: MUNICIPAL LIBRARY – GROUND FLOOR



FIGURE 79: MUNICIPAL LIBRARY –BASEMENT



## 10. CURRENT BUILDING CONDITIONS

### 10.1. CONSTRUCTIVE BUILDING CHARACTERISTICS

This is a detached building and the construction is a typical one of the period and region (see ANNEX C-1).

#### 10.1.1. ENVELOPE ELEMENTS

The walls consist of double brick and reinforced concrete for the load bearing structure. The walls are insulated with 5 cm of extruded polystyrene placed in between the two brick layers. The roof slab is insulated with 8 cm extruded polystyrene.

#### 10.1.2. WINDOWS

In all working areas there are opening windows with double glazing in aluminium frame.

The design overall U-value of the building envelope is 0.94 W/m<sup>2</sup>K. The following Table reports the U-values of the building envelope components as they are calculated in the thermal insulation study of the building.

TABLE 67: MUNICIPAL LIBRARY – U-VALUES

Element	Material	U-Value (W/m <sup>2</sup> K)
Wall	Double brick with 5 cm insulation in between	0.616
Load bearing structure	Reinforced concrete	0.627
Basement	Flat Reinforced concrete	0.570
Roof	Flat reinforced concrete with 8 cm insulation	0.419
Windows	Double glazing in aluminium frame	3.490

#### 10.1.3. AIRTIGHTNESS AND PATHOLOGIES

The building envelope does not present any problem with respect to airtightness. The envelope has many thermal bridges due to the type of wall construction as described earlier, and these problems have not been addressed adequately in the thermal study.

The windows and the doors of the building do not present any problems of air tightness and the building doesn't present other major pathologies.

## 10.2. ENERGY SYSTEMS

### 10.2.1. HVAC

Splits and floor standing air conditioning systems are used for heating and cooling the building via electricity. The ground and the first floor use extra oil radiators for heating.

The total installed capacity of the heating and cooling systems in the building is 32.4 kW.



FIGURE 80: SPIT A/C SYSTEM – EXTERNAL UNIT



FIGURE 81: A/C SYSTEM – INTERNAL UNIT MOUNTED ON THE WALL



FIGURE 82: FLOOR STANDING A/C SYSTEM –GROUND FLOOR



FIGURE 83: OIL RADIATOR –FIRST FLOOR

Table 68 summarizes the installed capacity of the building heating and cooling systems.

TABLE 68: INSTALLED CAPACITY OF THE A/C SYSTEMS

System	Power (kW)	Units	Total Power (kW)
PANASONIC A17 Split Unit	1.76	2	3.52
TOYOTOMI FST 240 Floor standing unit	7.04	2	14.08
Oil radiator	1.20	1	1.20
DAIKIN R60AV1 Split Unit	5.86	1	5.86
Oil radiator	2.50	1	2.50
PANASONIC A12 Split Unit	1.76	3	5.28

It should be noted that the reported EER and COP are nominal values provided by the manufacturers. However, because of the age and the inadequate maintenance of the devices the current performance of the A/C equipment is considered to be 1.7 for heating and 1.5 for cooling, according to the regulation for energy efficiency, KENAK.

#### 10.2.2. LIGHTING

Lighting is mainly supplied by fluorescent T8 lamps with magnetic ballast. The total installed capacity of lighting in the building is 3,992 W. All types of lighting systems that the building uses are presented below:

Type A: Ceiling lamp, with 2 lamps T8 Fluorescent of 58 W (2x58 W), length 150 cm. This light type is located in the ground and second floor.

Type B: Ceiling lamp, with 2 lamps T8 Fluorescent of 36 W (2x36 W), length 120 cm. This light type is located in the basement and first floor.

Type C: Ceiling lamp, with 2 lamps Compact Fluorescent of 18 W (2x18 W). This light type is located in the basement.

Type D: Circular lamp with one lamp of 35 W, located in WC. Type E: Oval wall lamp with one lamp of 60 W, located in every floor of the stairwell.

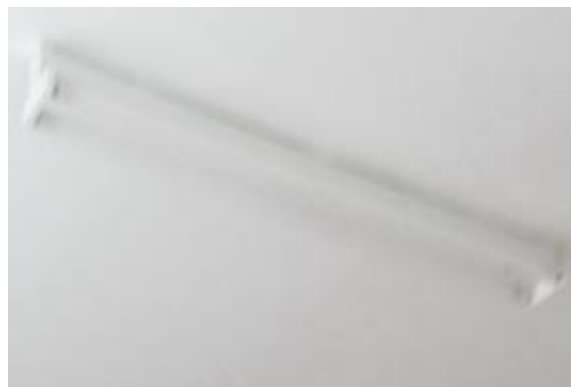


FIGURE 84: TYPE A, B -FLUORESCENT CEILING LAMP 2X58 W AND 2X36 W



FIGURE 85: TYPE C, D -COMPACT FLUORESCENT 2X18 W AND CIRCULAR LAMP 35 W

### 10.2.3. OTHERS

Other electrical loads are generated from ICT equipment such as pc units, printers, copy machines, and, other electrical devices (e.g. elevator, microwave, coffee machine and refrigerator). Their total power is 16,460 W.

TABLE 69: ELECTRICAL LOADS PER USE

Devices	Total Power (W)
Pc	4,500
Printer	270
Copy machine	1,600
Coffee machine	390
Refrigerator	600
Hi-fi	300
Microwave	800
Elevator motor	8,000
<b>Building Total:</b>	<b>16,460</b>

## 10.3. ENERGY CONSUMPTION AND ENERGY GENERATION

### 10.3.1. ELECTRICITY CONSUMPTION

All energy needs of the building are covered with electricity. Based in Energy Plus simulation the annual average consumption of the building is 47,647 kWh and the average annual total specific consumption is 94.03 kWh/m<sup>2</sup>.

The electricity consumption was disaggregated between uses by means of EnergyPlus building simulation code. The building model and its equipment and occupant profile are detailed in chapter 3.5.1, and ANNEXES C-2, C-3 and C-4. As shown in the next Figure the major consumption is for cooling, followed by heating and lighting.

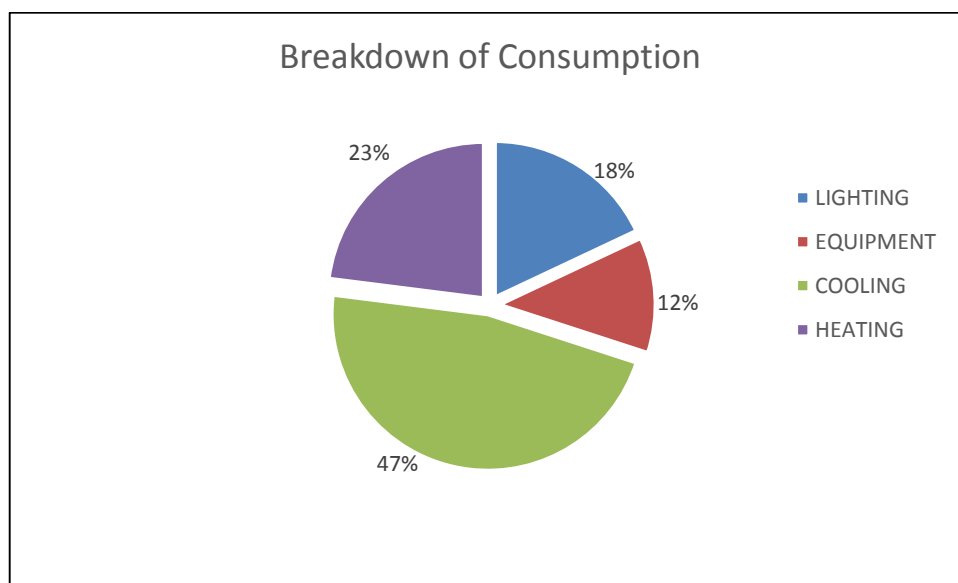


FIGURE 86: DISAGGREGATION OF ELECTRICITY CONSUMPTION BETWEEN USES

Measurements were carried out in order to check the three-phase distribution and the power factor ( $\cos\phi$ ) of the building. The three-phase instant consumption of the building was measured for each floor by using a clamp-on power meter (HIOKI). These measurements show the 3-Phases are not balanced and this can cause electrical current distribution problems or overheated electrical fuses. Also the power factor  $\cos\phi$ , was found to vary from 0.612 to 0.924 a range of values below the standard value of 0.95 the lowest permitted value for public buildings. The replacement of the current T8 fluorescent lamps with LED will contribute to the improvement of the power factor.

### 10.3.2. GAS/OIL CONSUMPTION

There is central system with oil boiler in the building which is currently out of use. It should be noted that the central heating pipe network is not insulated.

### 10.3.3. RENEWABLE ENERGY SOURCES

The building does not have any renewable energy sources.

### 10.3.4. OTHER GENERATION

The building does not have any other source of generation.

### 10.3.5. FINAL ENERGY CONSUMPTION AND CO<sub>2</sub> EMISSIONS

Based on Energy Plus simulation the yearly electrical consumption of the building converted to primary energy is 138,176 kWh and the corresponding CO<sub>2</sub> emissions are 47,122 kg CO<sub>2</sub>/kWh. The values were calculated using the following conversion factors in accordance with the Greek regulation of the energy performance of buildings, KENAK:

- electricity to primary energy – 2.9 (according to Greek regulation of the energy performance of buildings KENAK)
- electricity to CO<sub>2</sub> emissions – 0.989 kg/kWh (according to Greek regulation of the energy performance of buildings KENAK)

## 11. RENOVATION SCHEME

### 11.1. AIM OF THE RENOVATION PLAN

The aim of the renovation design about the Municipal Library of Alimos is in consistence with the requirements of the project. Regarding the energy consumption, the requirements are the total primary energy consumption to be reduced by at least 70% and the renewable energy systems which are installed in the building or nearby to it has to cover at least 50% of the final total consumption.

The holistic approach of the building renovation design includes extra insulation to the entire envelope, new low-e and thermal break windows. Also the natural ventilation has to be improved to avoid the overheating of the building and to achieve the appropriate internal air quality. Other strategies to reduce even more the energy demand are the night ventilation and the use of available daylight. After minimizing the energy demand the next step is to install very efficient systems to cover the needs of buildings for heating, cooling, mechanical ventilation and lighting. The last step of the renovation plan is to add renewable energy systems in order to reach the minimum possible level for the total energy demand.

The main difficulty regarding the interventions of this building is that the Municipality rents only a part of it and the three upper floors are residences. For this reason it is not easy to make changes if not all the owners agree. For example, in a building which has central heating system is not always easy to abolish this system and/or replace it with more flexible ones.

### 11.2. ENERGY DEMAND REDUCTION

#### 11.2.1. OPAQUE ENVELOPE

The building envelope is in good condition but has significant thermal bridges that increase the current overall U-value of the opaque part, by about 30%. This is due to the type of wall construction (insulation in – between the two brick layers) that makes the avoidance of thermal bridges difficult. Moreover, the current U-values of the external walls and roof are higher than those required by the new building regulation for energy efficiency, KENAK.

Therefore, the addition of external insulation was investigated as a means to improve the current conditions. Its impact on the year-round energy performance of the building was modelled by means of the simulation code EnergyPlus (see Ch. 11.5). For modelling purposes, an insulating material with 0.032 W/mK thermal conductivity was considered.

Three different values of thickness, namely, 5 cm, 7 cm, and 10 cm were successively studied. As can be seen Figure 87, by applying 5 cm of external insulation there is an annual decrease in heating of 537 kWh. Any further increase of the insulation thickness does not significantly affect the energy consumption. Additionally, the installation of 10cm would require not only an extra budget but extra structural works in order to be adequately supported.

Thus, the most suitable option is the addition of 5cm external insulation of 0.032 W/mK. Any other equivalent combination is equally suitable.

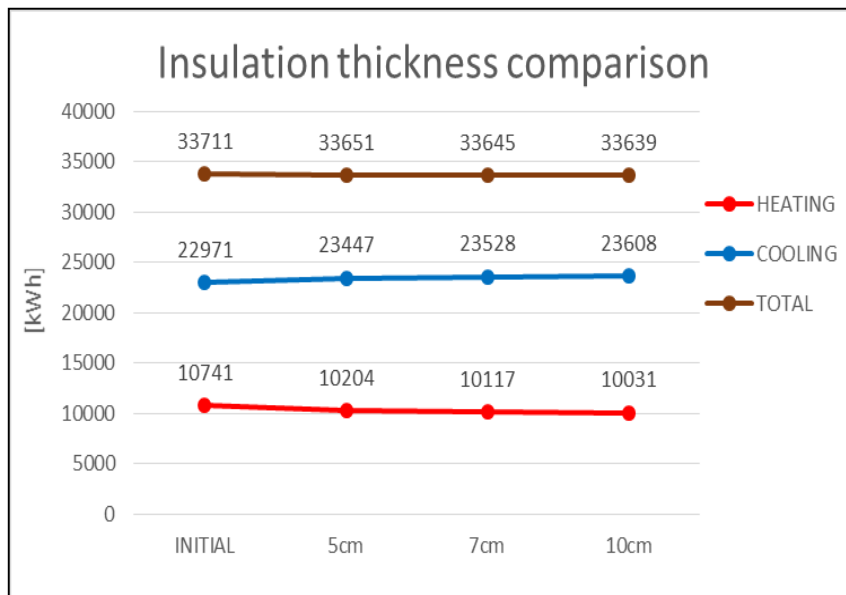


FIGURE 87: ENERGY PERFORMANCE ACCORDING TO DIFFERENT WIDTH OF INSULATION

As the previous figure shows the installation of external insulation do not decrease the heating load remarkably, the reasons are that the glazing area is quite big (43.4% of the total external surface above ground) and the envelope is insulated. So any further increase of the insulation thickness does not significantly affect the energy consumption. Additionally, installing 10 cm insulation would require not only extra budget but extra structural works in order to be sufficiently supported.

Further requirements for the selection of the external insulation system are:

- provide full waterproofing
- good vapour diffusivity
- fulfil all the requirements of the current regulation

The insulation materials EPS and natural mineral wool that were examined satisfies all technical requirements.

The application of the insulation has to follow very strict specifications in order to avoid potential failures of the system. Thermal bridging is one of the biggest issues which have to be tackled. Also, special attention must be given to the insulation and sealing of the openings. Finally, it is very important to have very good and tight application at ground level and generally in all areas where the insulating material is in contact with other elements of the building.



The addition of the investigated external insulation reduces the U-value of the walls from 0.616 W/m<sup>2</sup>K to 0.347 W/m<sup>2</sup>K and the U-value of the roof from 0.419 W/m<sup>2</sup>K to 0.250 W/m<sup>2</sup>K.

The performance of the building envelope was further improved with the addition of a thermal buffer zone installed in front of the main entrance to reduce infiltration by the frequent opening of the door.

The impact of these two measures on the building load is shown in the following Table.

TABLE 70: ANNUAL CONSUMPTION BEFORE AND AFTER ADD INSULATION

	Before	Retrofit	After Retrofit	
	Heating	Cooling	Heating	Cooling
Consumption (kWh)	10,741	22,971	10,204	23,447
Savings (kWh)	-	-	↓537	↑476
Savings (%)	-	-	↓5%	↑2%

### 11.2.2. OPENINGS

The existing glazing and frames with total U-value of 3.49 W/m<sup>2</sup>K will be replaced with low-e glazing and thermal break frame. After doing an investigation on different U-values (see Figure 88), it was decided that the optimum choice should have the following thermal properties:  $U_{\text{frame}}$  2.5 W/m<sup>2</sup>K,  $U_{\text{glazing}}$  1.1 W/m<sup>2</sup>K and the resulting window's U-value 1.8 W/m<sup>2</sup>K. A low-e coating is foreseen on the internal side of the external glass pane to reduce incoming heat. The glazing has 42% Solar Factor and 66% Light Transmission.

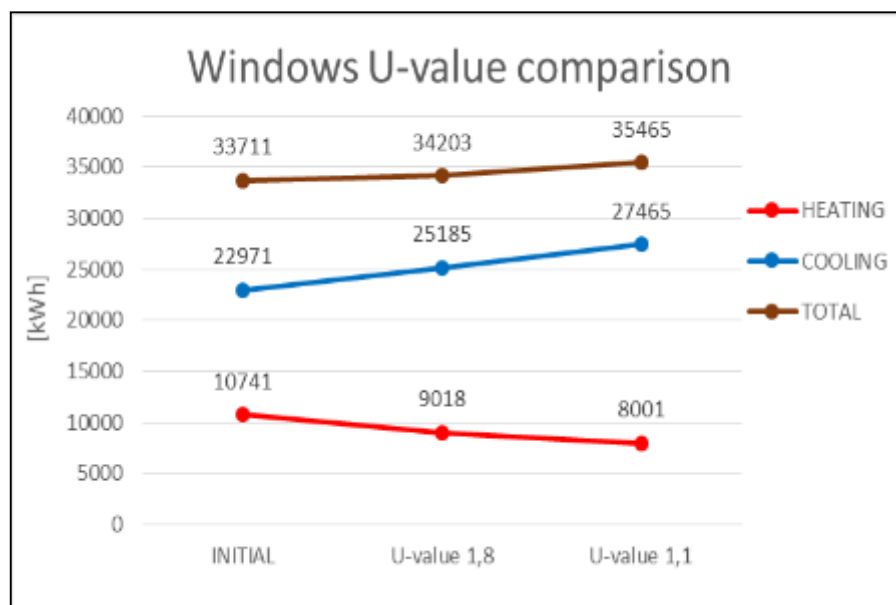


FIGURE 88: ENERGY PERFORMANCE ACCORDING TO DIFFERENT U-VALUE OF WINDOWS

As the previous figure shows the windows with lower U-value (e.g. 1.1 W/m<sup>2</sup>K) are not only more expensive but they increase the total energy consumption too. This happens because the windows with very low U-value delay the transmission of heat, generated from the high internal gains, resulting in an increase of energy demand for cooling.

In the following Table, the impact of the windows replacement on building's energy consumption is shown.

TABLE 71: ANNUAL CONSUMPTION BEFORE AND AFTER REPLACE THE WINDOWS

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	10,741	22,971	9,018	25,185
<b>Savings (kWh)</b>	-	-	↓ 1,723	↑ 2,214
<b>Savings (%)</b>	-	-	↓ 16%	↑ 10%

It is noted that the cooling demand has increased and so the overall year round energy consumption is increased.

### 11.2.3. SHADING

In this building, external shading devices will not be installed as they already exist devices or balconies which shade all the openings adequately.

### 11.2.4. NATURAL/NIGHT VENTILATION

In order to reduce further the energy demand for cooling natural/night-time ventilation is foreseen. This strategy will help to avoid the overheating of the building and to maintain the desired indoor conditions and indoor air quality.

Air vents equipped with dampers will be installed on the north and south façade of the building so as to achieve cross ventilation on each floor. The study concludes that on each floor, two air inlet openings with dampers have to be integrated into the lower zone of the north façade and two outlet openings in the upper zone of the south façade.

This system will operate during the night in summer (night ventilation) in order to cool the internal space by blowing fresh air inside, at a rate of 15 ACH. The inlet openings are equipped with small fans to assist air inflow in case natural ventilation does not suffice. Also, this system will operate during the day to offer the required rate of natural ventilation in periods when the outside air is cooler.

The ventilation openings will be connected with sensors for the external temperature and will operate only when the external temperature is lower than the internal. The use of these sensors ensures that the maximum saving in energy consumption for cooling will be achieved. The dampers will be insulated and airtight so to avoid any increase of heating in winter.

TABLE 72: ANNUAL CONSUMPTION BEFORE AND AFTER ADD NIGHT VENTILATION

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
Consumption (kWh)	10,741	22,971	10,741	19,296
Savings (kWh)	-	-	0	↓ 3,675
Savings (%)	-	-	0%	↓ 16%

### 11.3. ENERGY SYSTEMS

#### 11.3.1. LIGHTING SYSTEM

As previously presented the actual lighting system is mainly constituted by fluorescent T8 linear lamps with magnetic ballast. In total we have 54 fluorescent T8 lamps, 48 compact fluorescent lamps and 14 halogen lamps.

All lamps of the building will be replaced with new LED lamps. We will replace each lamp individually by keeping the already existing lighting fixtures.

Table 73 presents the already existing lamps and Table 74 shows the total power to be installed. The new installed total power is 1,536 W which is 39% of the initial power.

TABLE 73: TYPES AND QUANTITIES OF EXISTING LAMPS

Lamp Type	Quantity n	Lamp W	Total W
Fluorescent Linear T8 150cm	27	58	1,566
Fluorescent Linear T8 120cm	27	36	972
Compact Fluorescent	48	18	864
Halogen lamp	10	35	350
Halogen lamp	4	60	240
		<b>Total:</b>	<b>3,992</b>

TABLE 74: TYPES AND QUANTITIES OF LAMPS TO BE INSTALLED

Lamp Type	Quantity n	Lamp W	Total Power W
LED Tube Glass T8 150cm	27	22	594
LED Tube Glass T8 120cm	27	18	486
LED Compact E14	48	6	288
LED E27	14	12	168
		<b>Total:</b>	<b>1,536</b>

Additionally, the wiring of fixtures will be replaced to allow for better zoning of the room lighting. Also, daylight sensors will be installed on the luminaires located close to the windows of the 3 upper floors so that artificial lighting be turned off automatically when the desired lighting levels are reached. In total sixteen (16) daylighting sensors will be installed. According to EnergyPlus simulation, this will give an additional reduction of 22% of the total consumption for lighting. An additional benefit with the replacement of the T8

lamps with LED is the improvement of the power factor because the operation of the latter does not require any magnetic ballast.

Table 75 presents the yearly consumption for lighting, as well as the percentage of achievable savings including the savings entailed by the use of LUX sensors. As can be seen, the savings are 60%.

TABLE 75: YEARLY CONSUMPTION WITH LED LIGHTING AND LUX SENSORS

	Actual	Led
Consumption (kWh)	7,846	3,766
Consumption + LUX sensors (kWh)		3,164
Savings (kWh)	-	4,682
Savings (%)	-	60%

### 11.3.2. HVAC SYSTEM

The existing systems will be replaced with new A/C systems more efficient [EER 3 – 4.4] and they will be used only for cooling. In all windows and doors will be placed an on/off touch connected with each A/C unit. If a window is open, it will stop the operation of the corresponding A/C, as long as it works.

In the following table are presented the technical characteristics and the units of the new A/C systems:

TABLE 76: A/C SYSTEMS

System	Power (kW)	Units	Total Power (kW)	EER
<b>Basement</b>				
A/C Split Unit	5.0	1	5.0	3.0
A/C Split Unit	2.5	1	2.5	4.4
<b>Ground Floor</b>				
A/C Split Unit	7.0	2	14.0	3.8
<b>First Floor</b>				
A/C Split Unit	5.0	2	10.0	3.0
<b>Second Floor</b>				
A/C Split Unit	2.0	2	4.0	3.6
A/C Split Unit	2.5	1	2.5	4.4
A/C Split Unit	3.5	1	3.5	4.0
<b>Total:</b>			<b>41.5</b>	

Regarding the heating of the building, there is central system with oil boiler which is currently out of use but it will be reactivated after the renovation. As the cost of installing a new Pellet boiler is high it was considered that the optimum choice is the conversion of the old boiler to a new Pellet boiler. The renovation is simply a matter of removing the existing oil burner and replacing it with a new automatic feeding wood pellet burner. The old heating system will be transformed to a more environmental friendly one and with less CO<sub>2</sub> emissions. Also the central heating system pipes will be insulated with 9 mm insulation reducing loses and the central heating water pump will be replaced with a new one inverter technology reducing the water pump's electricity consumption.

Table 77 presents the annual consumption with the existing HVAC system for heating and cooling and the Retrofit scenario. As can be seen, the Retrofit ensures 68% of energy savings for cooling. The consumption for heating is 11% higher which is affordable as the pellet is cheap fuel. Also the radiators ensure better internal conditions such as thermal comfort and maintain suitable humidity compared to the A/C splits.

TABLE 77: ANNUAL CONSUMPTION BEFORE AND AFTER RETROFIT

	Before Retrofit		After Retrofit	
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	10,741	22,971	11,934	7,178
<b>Savings (kWh)</b>	-	-	↑1,193	↓15,793
<b>Savings (%)</b>	-	-	↑11%	↓68%

## 11.4. RENEWABLE ENERGY SOURCES

### 11.4.1. PV GENERATION

In order to ensure that 50% of the consumed energy in the building is generated by renewable energy sources, a photovoltaic system of 5.73 kWp will be installed on the building's roof.

The PV panels will be placed in the south-facing with a fixed slope of 25°. The photovoltaic system will be connected to the low voltage grid via three phase power.

The generated electricity will be supplied to the Utility (The Public Power Corporation), according to the Greek regulation "Net-metering". The prescribed procedure is the following. In each measurement cycle and billing, the electricity consumed by the building will be offset with the electricity generated by the photovoltaic system. In case there is excess energy will not be lost, but will be credited to the next billing period. At the end of the year the excess is cleared without compensation.

The picture below shows the PV panels on the roof.



FIGURE 89: PV PANELS INSTALLED ON THE ROOF

The PV system will consist of eighteen (18) Photovoltaic panels under nominal power of 318 Wp each. The connection to the low voltage grid will be done three (3) DC/AC inverters with rated output of 2,100 W each and the total rated power of the PV system is 5.73 kWp.

The production of the PV system was estimated using PVGIS /3/, a software developed by The Joint Research Centre of the European Commission in ISPRA, Italy.

The monthly and annual solar radiation in the area based on the PVGIS database is presented in the following table.

TABLE 78: SOLAR RADIATION VALUES AT THE AREA OF ALIMOS - SOURCE: PVGIS DATABASE (KWH/ M<sup>2</sup>/MONTH) - 25°

MONTH	Irradiation at inclination: 25° deg (kWh/m <sup>2</sup> /month)
JANUARY	91
FEBRUARY	95
MARCH	140
APRIL	168
MAY	193
JUNE	205
JULY	210
AUGUST	201
SEPTEMBER	178
OCTOBER	135
NOVEMBER	89
DECEMBER	79
<b>YEAR</b>	<b>1,784</b>

PVGIS set the Azimuth angle from -180° to 180°, East -180° and South 0°. The PV system will be installed at 30° west of south and 25° inclination from horizontal.

According to PVGIS the 5.73 kW will produce **8,040 kWh** per year. In practice, this figure is expected to be exceeded by 15%. This argument is based on the recorded yield of the numerous PV installations in the area. However, in order to be on the safe side the PVGIS calculated value is used for the energy balance calculations and economic appraisal.

The monthly energy production and the PVGIS estimation are shown in the next figures.



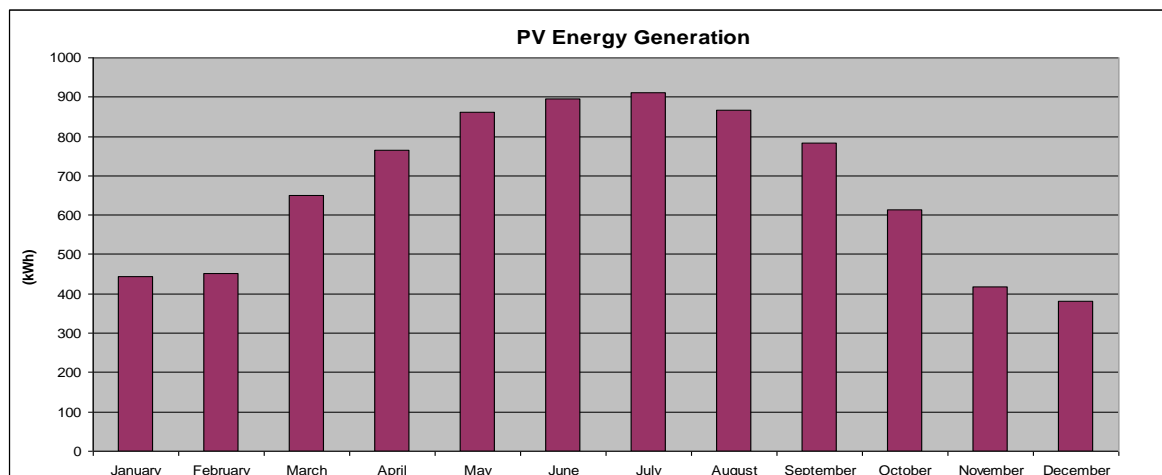


FIGURE 90: ENERGY INJECTED INTO GRID FROM THE PV SYSTEM

#### 11.4.2. PELLET BOILER

In order the 50% of the final energy consumption in the building to be covered by renewable energy systems, it was decided besides the installation of PVs the use of Pellet boiler. As it is mentioned on the paragraph "HVAC System" the heating of the building will be based on the use of Pellets which is a biomass energy source converted via the boiler into heating.

#### 11.4.3. THERMOSTAT AND POWER METER

The use of a Thermostat in every room of the building will ensure that the desired internal air temperature will be stable and will prevent the excess use of energy.

Table 79 presents the achievable savings, with the Thermostats integration.

TABLE 79: ENERGY CONSUMPTION SAVINGS WITH THE USE OF THERMOSTATS

	Before Retrofit		With Thermostats	
	Heating	Cooling	Heating	Cooling
<b>Consumption (kWh)</b>	10,741	22,971	6,874	16,999
<b>Savings (kWh)</b>	-	-	↓3,867	↓5,972
<b>Savings (%)</b>	-	-	↓36%	↓26%

Additionally in order to record and storage the energy consumption of the A/C system, lighting and pc units so as to detect the energy intensive units we will install power meters to the electrical board of each floor.

#### 11.4.4. SOLAR THERMAL COLLECTORS

The building's needs for hot water are negligible and so there is no renovation plan regarding the use of solar thermal collectors.

### 11.5. TOTAL IMPACT OF THE RENOVATION SCHEME

#### 11.5.1. ENERGY PERFORMANCE

The energy analysis of the building was carried out using the EnergyPlus v7.2 building simulation code. The building was described in due detail following the architectural drawings and results from the energy audit

regarding lighting, equipment, and, building and systems operation profile. Also, the surrounding buildings were placed on the model in order to take into account the shadings which created by them throughout the year. The specifications of the construction materials which were inputted to the software are according to the building's studies (e.g. thermal insulation study) and the onsite inspections. Additionally, other parameters which are needed for the simulations such as internal environment (temperature, ventilation, and infiltration) and internal heat loads of users and devices were taken from the Greek regulation for the energy performance of buildings KENAK. The parameters used for the simulations are shown in ANNEX C-2, C-3 and C-4.

The weather data used in EnergyPlus for the simulation are taken from a meteorological station which is located at Ellinikon nearby Alimos {N 37° 54'} {E 23° 43'}, 15m above sea level. The comparison between the weather data from HNMS (Hellenic National Meteorological Service) and those that EnergyPlus uses are in good agreement.

Two scenarios were simulated. In the first scenario, the thermostat set points are according to the Greek regulations, namely, 20 °C for heating and 26 °C for cooling. The second scenario is more realistic regarding the building's operational profile and the thermostats' set-points are set at 22 °C for heating and 24 °C for cooling. These values result from the site inspection.

The consumptions for the first scenario, second scenario and the actual one from Utility invoices are displayed below. It is noted that the heating and cooling consumptions are calculated based on the cooling and heating demands resulted from EnergyPlus and considering that COP and EER of the building's air conditioning systems are equal to 1.7 and 1.5 respectively. This is in line with the national regulation, KENAK, for old air-conditioning systems that are not properly maintained.

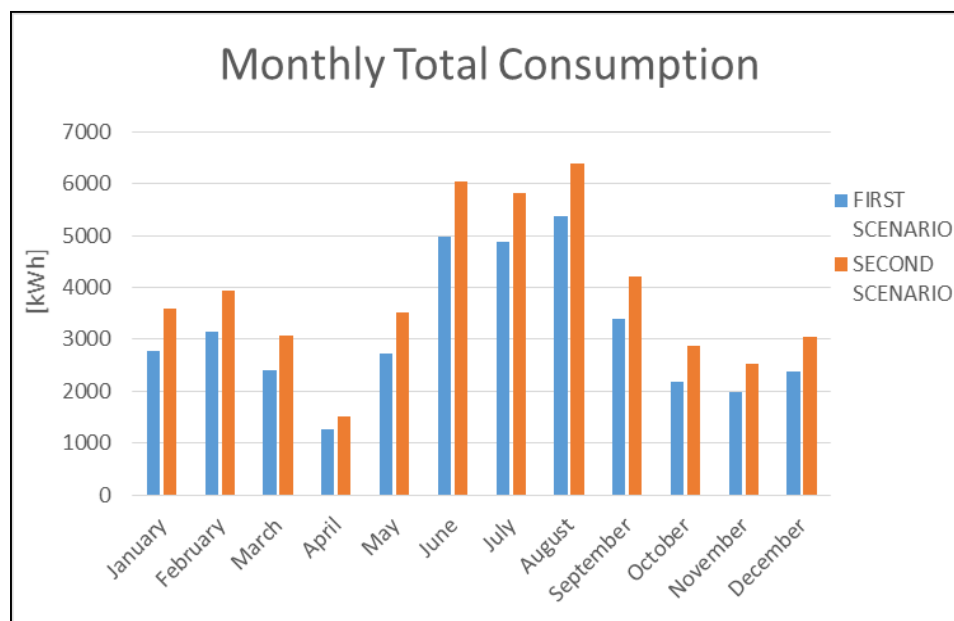


FIGURE 91: COMPARING ENERGYPLUS RESULTS WITH PPC INVOICES MONTHLY CONSUMPTIONS

TABLE 80: ANNUAL TOTAL ELECTRICITY CONSUMPTION

1 <sup>st</sup> SCENARIO (kWh)	2 <sup>nd</sup> SCENARIO (kWh)
37,508	46,559

The change of the thermostat set points increased the consumption in the 2<sup>nd</sup> Scenario for heating and cooling by 24%. These results are more realistic and very similar to the real consumptions of the building. The difference between the realistic and the actual consumption is negligible if we take into account that the actual ventilation rate is higher than the required standard, which is imported to EnergyPlus. So all the interventions will applied on the second scenario's model.

The following table shows how each intervention affect the energy consumption of the building. The changes are displayed separately for heating, cooling, lighting and total in order each intervention to be evaluated in a very detailed way.

The calculations are based on the optimum choices regarding all the interventions as they presented in paragraphs 3.2 to 3.4. The selected renovation plan is the following:

- Add external insulation of 5 cm thickness and U-value 0.032 [W/mK]
- Replacement of the windows with total U-value 1.8 [W/mK], Solar Factor of 42% and Light Transmission 66%
- Replacement of all lamps with LEDs
- Replacement of the existing split unit with new more efficient [EER 3 – 4.4] for cooling
- Replacement of the existing heating central system which has oil boiler with a pellet boiler
- Add night ventilation of 15 ACH
- Add power meters in each electrical board in order to monitor and record the energy consumption of all systems of the building
- Install PVs on the roof 5.52 kWp

TABLE 81: ENERGY SAVINGS FROM EACH INTERVENTION

		HEATING	COOLING	LIGHTING	ELECTRICITY
		ENERGY SAVINGS [%]	ENERGY SAVINGS [%]	ENERGY SAVINGS [%]	POWER [kWh/year]
BUILDING ENVELOPE	<b>External Insulation</b> U-value= 0.032 W/mK d= 5 cm	5 ↓	2 ↑	-	
	<b>Windows</b> Low-e, U-value= 1.8 W/mK	30 ↓	10 ↑	-	
HVAC	<b>Pellet boiler</b> COP= 0.9	50 ↓	-	-	
	<b>A/C</b> EER= 3.2	-	53 ↓	-	
	<b>Thermostats/Power meters</b> standard setpoints	36 ↓	26 ↓	22 ↓	
	<b>Night Ventilation</b>	-	16 ↓	-	
LIGHTING	<b>LED</b>	-	-	62 ↓	
	<b>LUX sensors</b>	-	-	22 ↓	
RES	<b>PV</b> on the roof 5.76 kWp				8,041

As the results show some interventions have contradictory effects on heating and cooling consumption (e.g. external insulation) and so before the final decision cannot be taken without taking into consideration the absolute effect on the total energy consumption. At the same time the impact that each intervention has on other parameters except for energy, like internal conditions, users comfort, etc. has to be evaluated too.

The following table shows the accumulative effect on the primary energy consumption of the building during the implementation of the renovation plan. The changes are displayed separately for heating, cooling, lighting and total in order the renovation plan to be evaluated in different phases.

TABLE 82: ACCUMULATIVE ENERGY SAVINGS FROM THE INTERVENTIONS

	Heating		Cooling		Lighting		Total	
	[ kWh]	[%]	[ kWh]	[%]	[ kWh]	[%]	[ kWh]	[%]
<b>INITIAL</b>	31,148	-	66,615	-	24,433	-	122,195	-
<b>INSUL</b>	29,590	-5%	67,997	2%	24,433	0%	122,020	0%
<b>WIND-INSUL</b>	18,894	-36%	76,813	13%	24,433	0%	120,140	-2%
<b>INSUL-WIND-NV</b>	18,894	0%	59,301	-23%	24,433	0%	102,628	-15%
<b>INSUL-WIND-NV-PELLET/AC</b>	12,307	-35%	27,797	-53%	24,433	0%	64,537	-37%
<b>INSUL-WIND-NV-PELLET/AC-THERM</b>	9,589	-22%	20,069	-28%	24,433	100%	54,090	-16%
<b>INSUL-WIND-NV-PELLET/AC-THERM-LIGHTING</b>	9,589	-22%	20,069	-28%	7,242	-70%	36,900	-43%

<b>INSUL:</b> extrenal insulation	<b>AC:</b> new air conditions
<b>WIND:</b> windows	<b>LIGHTING:</b> led
<b>NV:</b> night ventilation	<b>LIGHTING:</b> led
<b>PELLET:</b> pellet boiler	

These data shows how the different interventions interact to each other and to the primary energy consumption from different uses. This information is very important as the final condition of the building is not just the sum of all different savings and so it is not easy to be estimated without the appropriate simulations.

#### 11.5.2. ENVIRONMENTAL PERFORMANCE

The following table is shown the initial and the final consumption after implementing all the proposed interventions in the building.

TABLE 83: ENERGY CONSUMPTION BEFORE AND AFTER RENOVATION PLAN

ENERGY	Heating		Cooling		Lighting		Total	
	[ kWh]	[%]	[ kWh]	[%]	[ kWh]	[%]	[ kWh]	[%]
<b>INITIAL</b>	10,741	-	22,971	-	8425	-	42,136	-
<b>FINAL</b>	9,589	-11%	6,920	-70%	2,497	-70%	19,006	-55%

As it is noticed in the previous table the energy for heating is quite high compared with those for cooling and lighting. The reason is that for space heating is used a pellet boiler which has COP 0.9 and not a more efficient HVAC system like heat pump. But at the same time, the use of pellet leads to a significant reduction of the primary energy and CO<sub>2</sub> emissions (see Table 84).

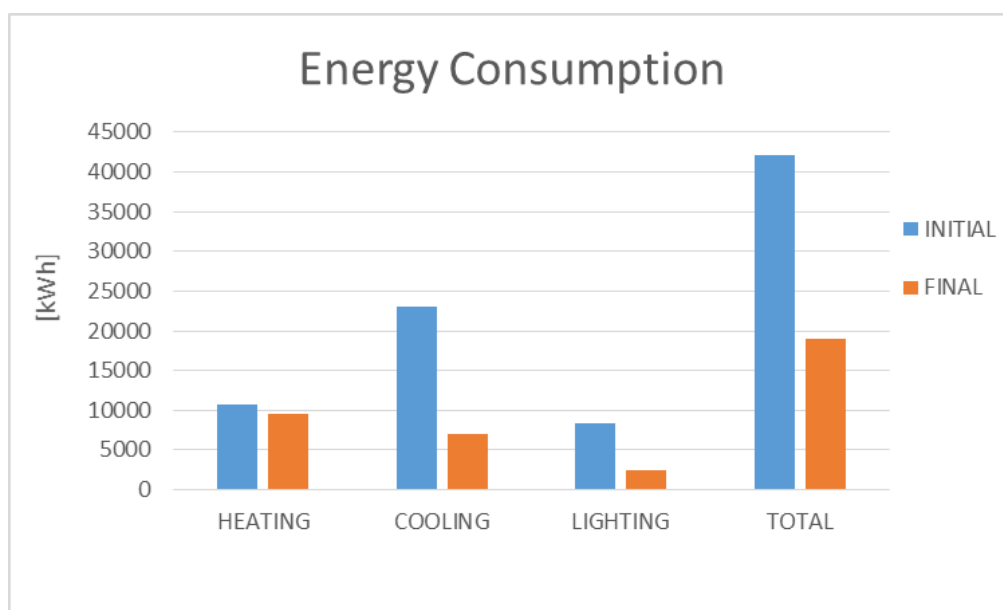


FIGURE 92: COMPARISON OF ENERGY CONSUMPTION FOR EACH USE

The results were also assessed in terms of primary energy and CO<sub>2</sub> emissions considering the following conversion factors which are taken by the Greek regulation:

The results were also assessed in terms of primary energy and CO<sub>2</sub> emissions considering the following conversion factors which are taken by the Greek regulation for the energy performance of buildings:

- electricity to primary energy – 2.9
- electricity to CO<sub>2</sub> emissions – 0.989 kg/kWh
- biomass to primary energy – 1
- biomass to CO<sub>2</sub> emissions – 0 kg/kWh

TABLE 84: PRIMARY ENERGY CONSUMPTION AND CO<sub>2</sub> EMISSIONS BEFORE AND AFTER RENOVATION PLAN

	Heating		Cooling		Lighting		Total	
	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]	[kWh]	[%]
<b>INITIAL (primary energy)</b>	31,148	-	66,615	-	24,433	-	122,195	-
<b>FINAL (primary energy)</b>	9,589	-50%	20,069	-55%	7,242	-70%	36,900	-70%
<b>INITIAL (CO<sub>2</sub> emissions) [kg CO<sub>2</sub>]</b>	10,622	-	22,718	-	8,332	-	41,673	-
<b>FINAL (CO<sub>2</sub> emissions) [kg CO<sub>2</sub>]</b>	0	-100%	6,844	-70%	2,470	-70%	9,314	-78%

After the renovation the primary energy consumption is finally reduced by 21,559 kWh for heating, 46,546 kWh for cooling, 17,191 kWh for lighting and 85,295 kWh in total.

Also, Table 84 shows the comparison regarding consumption and the savings in primary energy and CO<sub>2</sub> emissions before and after the renovation. The achieved savings are 70% in total primary energy and 78% in CO<sub>2</sub> emissions which are 85,295 kWh and 32.36 tons of CO<sub>2</sub> emissions respectively. Also, the proposed PVs system produces 8,041 kWh/year which means that 63% of the total annual demand for electricity will be covered by this system. The total demand for electricity refers to the consumptions for cooling and lighting.

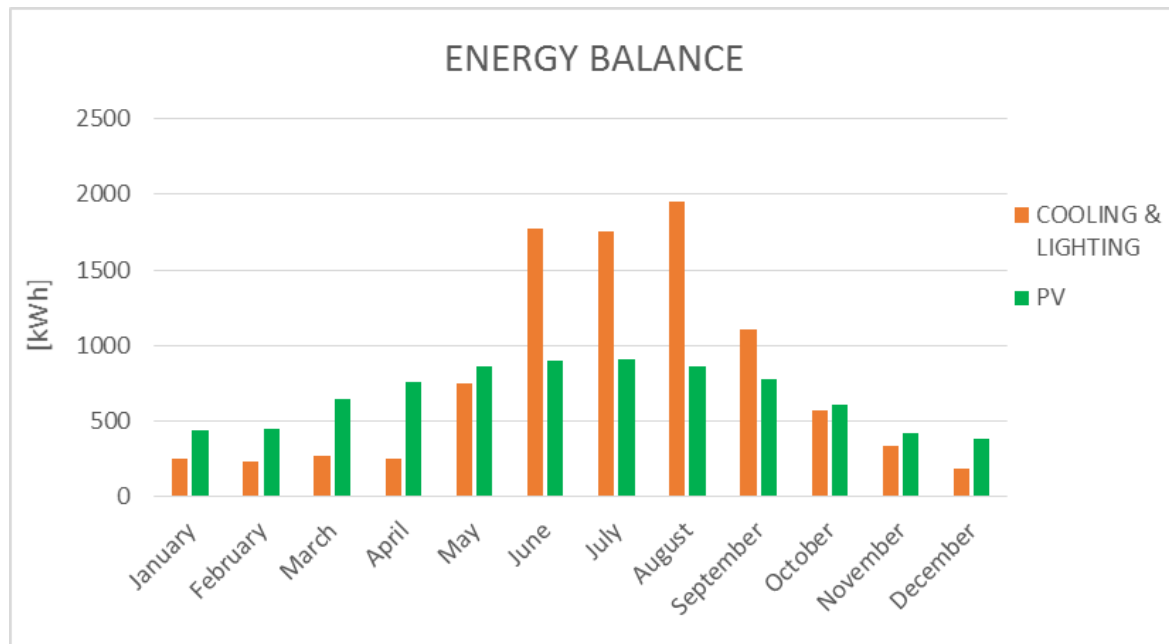


FIGURE 93: ENERGY INJECTED INTO GRID FROM THE PV SYSTEM

As it is shown on the graph above, the energy production of the PV system in months January to April and November to December surpasses the lighting load (there is no cooling in winter months) and can cover other electric uses. If the total electric use in the Library is lower than the PV production then according to “net – metering” regulation, the surplus is balanced in the months with greater consumption (e.g. June to September).

Additionally, the energy consumption for heating is covered by biomass which means that in total 89% of the building’s energy demand is covered by renewable energy sources.

Finally, after subtracting the energy which is produced by the PVs system annually from the final demand of electricity, there is a further decrease of the primary energy to 13,581 kWh which means that the total savings are 108,614 kWh. This leads to supplementary savings of the CO<sub>2</sub> emissions as well by 7.95 tons and in total by 40.31 tons.



## FINAL RENOVATION

<b>Building Envelope</b>	<ul style="list-style-type: none"> <li>External insulation</li> <li>Low-e glazing windows</li> <li>Natural and Night Ventilation</li> </ul>	Primary Energy Consumption for Heating	18.9 kWh/m <sup>2</sup>
		Primary Energy Consumption for Cooling	39.5 kWh/m <sup>2</sup>
<b>Energy Systems</b>	<ul style="list-style-type: none"> <li>AC System</li> <li>Central system for heating</li> <li>LED lighting with Lux sensors</li> <li>Control system (thermostat)</li> </ul>	Primary Energy Consumption for Lighting	14.3 kWh/m <sup>2</sup>
		Energy production from PV	15.9 kWh/m <sup>2</sup>
		Primary Energy Savings from Interventions	70.0%
<b>RES</b>	<ul style="list-style-type: none"> <li>PV system</li> <li>Wood pellet boiler</li> </ul>	Energy Savings with RES	89.0%
		Total Primary Energy Savings	96.7%

## 12. ECONOMIC EVALUATION OF THE PROPOSED RENOVATION SCHEME

### 12.1. ASSUMPTIONS AND COST FIGURES

The cost of the interventions is estimated based on current market prices of the equipment and the installation works. Special meetings with suppliers were held to present the project and request offers for the preliminary renovation design. Offers were collected and assessed.

For each intervention, the cost has been calculated as the sum of costs for equipment, installation, operation and maintenance. These values have been organised in an Excel file prepared by Sinloc, a partner of the CERTuS consortium /4/. ANNEX C-6, gives the cost information.

The economic appraisal of the renovation design was performed by means of a tool produced by ETVA VIPE, also a partner of the consortium. A detailed description of the tool is presented in /4/. The appraisal can be performed for each intervention separately and, for the whole design. The tool also allows to examine various financing schemes ranging from single financing source to multiple, combining bank loans, ESCOs, subsidies, municipality's own equity.

As output, it gives the NPV, IRR and payback time for each financing source and for the total investment. Also the cash flow over the examined period is given.

The data used for the calculations are tabulated below (Table 85).

TABLE 85: DATA FOR THE ECONOMIC EVALUATION OF INTERVENTIONS

PARAMETER	INTERVENTION							
	Insulation	Windows	AC	Boiler	N. Vent.	Control System	Lighting	PV
Cost of intervention (€)	38,007	39,987	16,605	2,276	4,920	3,700	2,645	9,840
O&M cost (€)(*)	0	0	6,534	3,267	3,267	3,267	2,234	6,534
Extraordinary maintenance cost (€) (*)	0	1,009	797	1,359	1,352	3,398	0	2,789
Cost of energy before( €)	7,585	7,585	7,585	7,585	7,585	7,585	7,585	7,585
Cost of energy After (€)	7,574	7,418	5,388	7,002	6,923	2,726	6,644	6,137
Change of energy cost over examined period (**)	1%	1%	1%	1%	1%	1%	1%	1%
Equipment efficiency drop over examined period	0%	0%	20%	20%	20%	0%	0%	20%
Interest rate	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
Discount rate	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%	3.75%
Average inflation rate over examined period	2%	2%	2%	2%	2%	2%	2%	2%

(\*) This is the cost over the lifetime of the intervention that is taken equal to 25 years for all except for the lighting that is 10 years.

(\*\*) The examined period is 25 years for all interventions except of lighting which is 10 years.

## 12.2. RESULTS

The Table below (Table 86), gives the payback time, NPV and IRR calculated for each intervention separately and for the complete design (all interventions).

TABLE 86: ECONOMIC EVALUATION OF INTERVENTIONS

	Insulation	Windows	AC	Boiler	N. Vent.	Control system	Lighting	PV	ALL Interventions
Payback period (years)	23	23	8	5	8	0	3	8	23
NPV	-37,768	-37,292	14,815	4,443	3,102	78,737	3,316	8,137	-46,408
IRR	-15.85%	-9.44%	10.96%	19.19%	9.28%	129.14%	24.49%	10.72%	-0.10%

The following figure compares the payback period of each intervention as a separate investment and the combination of all the interventions.

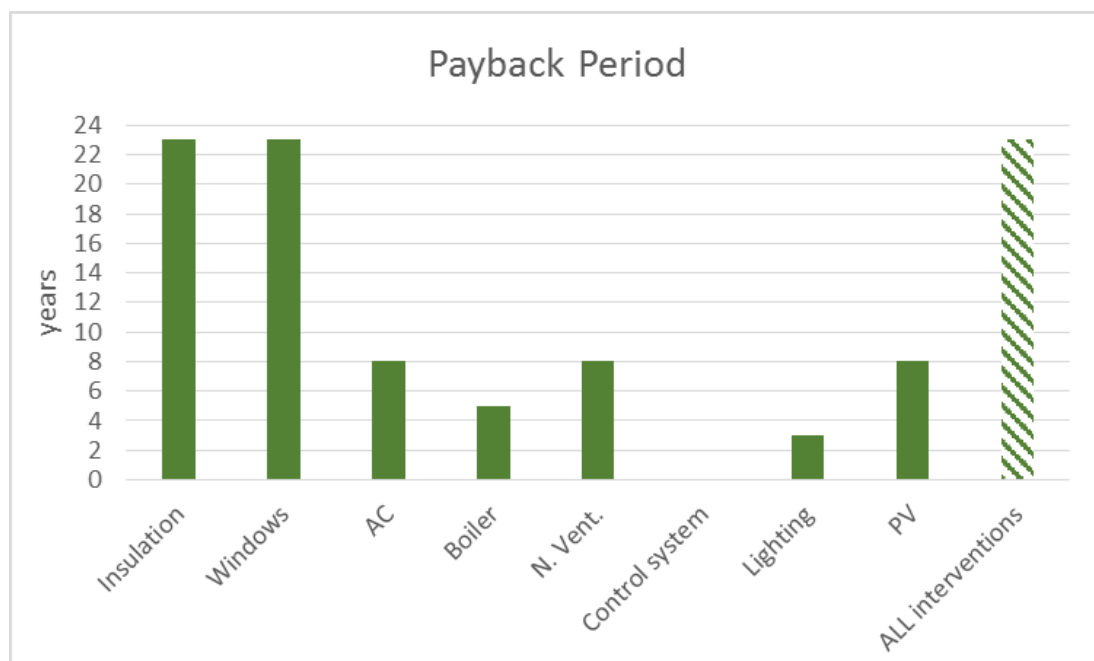


FIGURE 94: PAYBACK PERIOD FOR EACH INTERVENTION

As can be seen from the figure above if all interventions are applied they have a payback time of 23 years. The interventions relevant to the envelope have lengthier payback times and so they increase the overall payback time. Although these envelope interventions have side benefits such as the prolonged lifetime of the building and the increase of asset value, the current economic appraisal focuses strictly on the annual balance of costs and savings. Thus at the period of 25 years (the common expected life span for building interventions) the net present value of the building envelope interventions is negative. This means that

unless there is a suitable subsidy these interventions are not currently financially attractive. However, in the future this situation may change if the building needs or the market conditions change.

The economic appraisal of three alternative scenarios was carried out without the building envelope improvement. The first one excludes only the external insulation, the second one only the replacement of the glazing and the third one excludes both interventions. The comparison of the scenarios with the initial renovation scheme is displayed in the following table.

TABLE 87: COMPARISON OF ALTERNATIVE RENOVATION SCENARIOS

Primary Energy	Heating [kWh]	Cooling [kWh]	Total [kWh]	Percentage Of Energy Increase [%]
<b>Complete Renovation Scheme</b>	9,589	20,069	29,658	-
<b>Scenario 1</b> (without external insulation)	10,709	19,382	30,091	1 %
<b>Scenario 2</b> (without glazing replacement)	12,218	18,525	30,742	4 %
<b>Scenario 3</b> (without external insulation and glazing replacement)	12,957	18,268	31,225	5 %

Table 87 shows that the increase of the energy consumption in the three alternative scenarios is not significant. An increase in the insulation causes heating demand to decrease but contrarily it increases cooling demand. Thus the annual balance is lower but not significantly.

The economic evaluation of these alternative scenarios is shown in Figure 95 and Figure 96.

As can be seen, the high cost of the external insulation and windows replacement combined with the low increase in energy needs make scenario 3 the most feasible one.

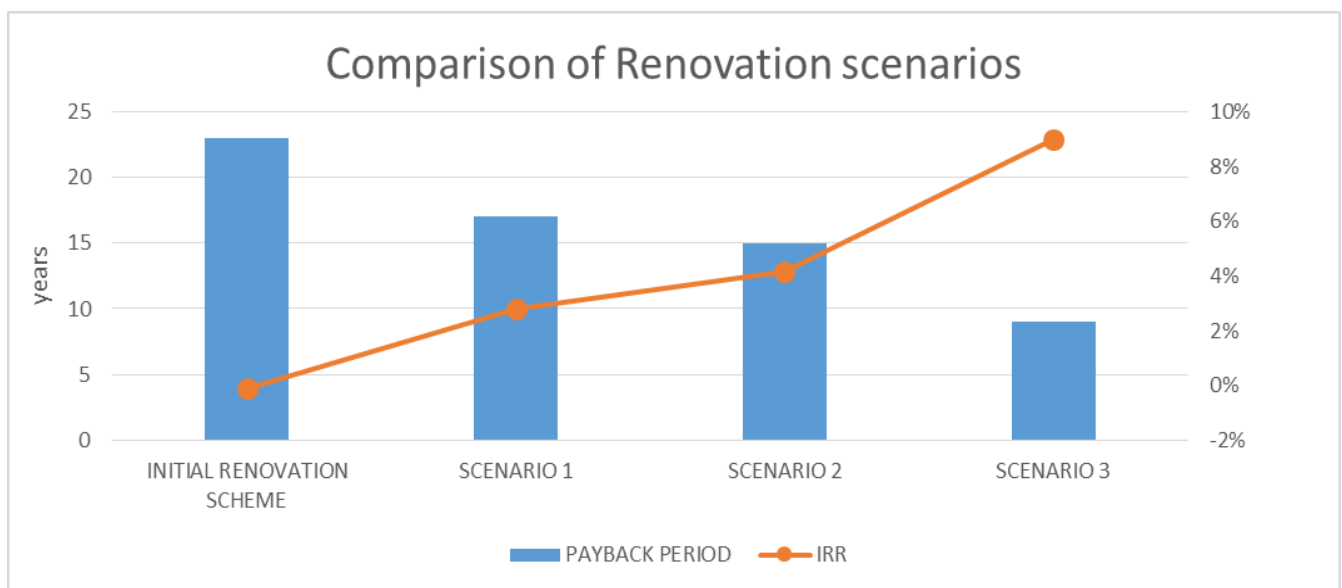


FIGURE 95: PAYBACK PERIOD AND IRR FOR ALL RENOVATION SCENARIOS

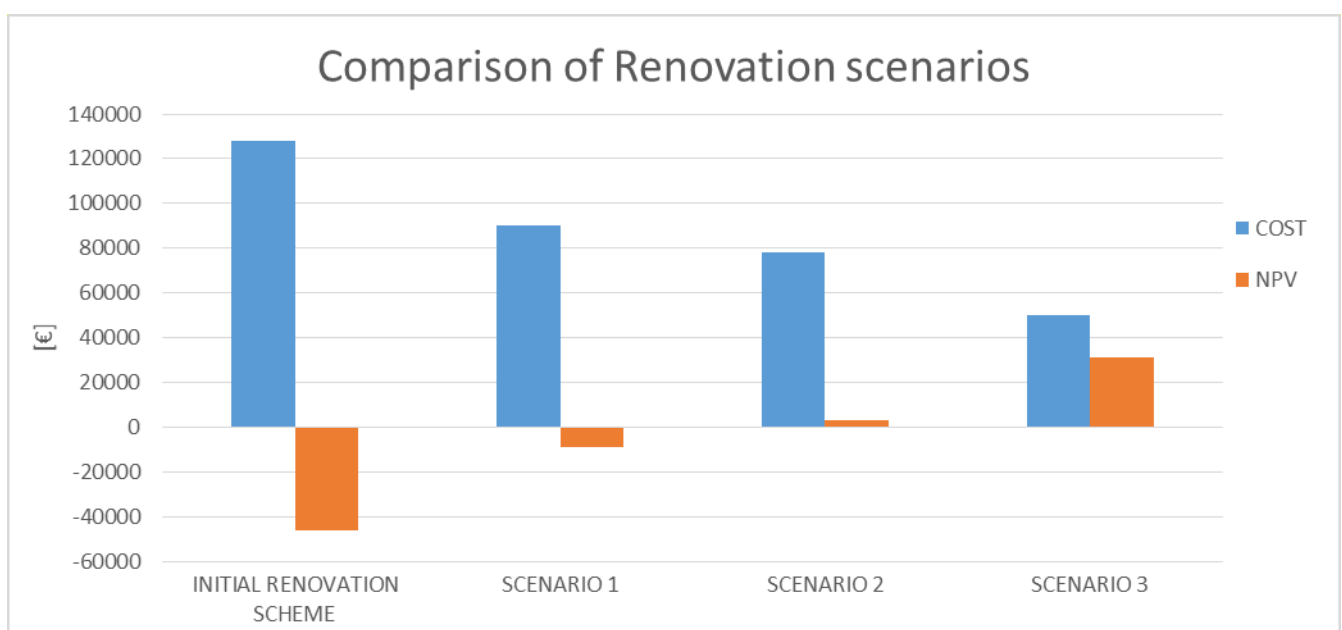


FIGURE 96: COST AND NPV FOR ALL RENOVATION SCENARIOS

The following Table (Table 88), summarises the results of the 4 scenarios.

Regarding RES contribution the percentages that Table 88 displays refer only to energy produced from PVS. The total percentage of RES contribution is even higher as the total heating needs are covered by wood biomass which is considered as RES too.

TABLE 88: COMPARISON OF ALTERNATIVE RENOVATION SCENARIOS

Primary Energy	Energy Savings (%)	Res Contribution (%)	Cost (€)	Payback Period (years)
<b>Complete Renovation Design</b>	70.0	63	127,994	23
<b>Scenario 1</b> (without external insulation)	69.0	61	89,987	17
<b>Scenario 2</b> (without glazing replacement)	69.0	62	77,994	15
<b>Scenario 3</b> (without external insulation and glazing replacement)	68.5	60	50,000	9

Even with scenario 3, the energy consumption for heating, cooling and lighting is reduced by 68.5% and so, it is very close to the renovation energy target requiring reduction over 70%. At the same scenario 3, the RES contribution is 100% for heating and 90% of the remaining electricity needs and so the target which is at least 50%, is satisfied.

Therefore, if the building envelope improvement cannot be funded under the current conditions, they can be excluded from the renovation plan. Probably they can be implemented at a later time or when economic conditions are more favourable.

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## REFERENCES

- /1/ EnergyPlus, is an energy simulation program which models heating, cooling, lighting, ventilation, other energy flows, and water use. It is developed by U.S Department of Energy.  
<http://apps1.eere.energy.gov/buildings/energyplus/>
- /2/ Autodesk Ecotect-Weather Manager, is a utility program for the creation, conversion and management of tightly formatted weather data files. It is developed by Autodesk.
- /3/ PVGIS, Photovoltaic Geographical Information System, a software developed by The Joint Research Centre of the European Commission in ISPRA, Italy.  
<http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php>
- /4/ CERTUS Deliverable D2.5 "Twelve economic evaluation reports"



## ANNEX A - CITY HALL

### ANNEX A-1: BUILDING DRAWINGS

Below are the rest drawings of the building.

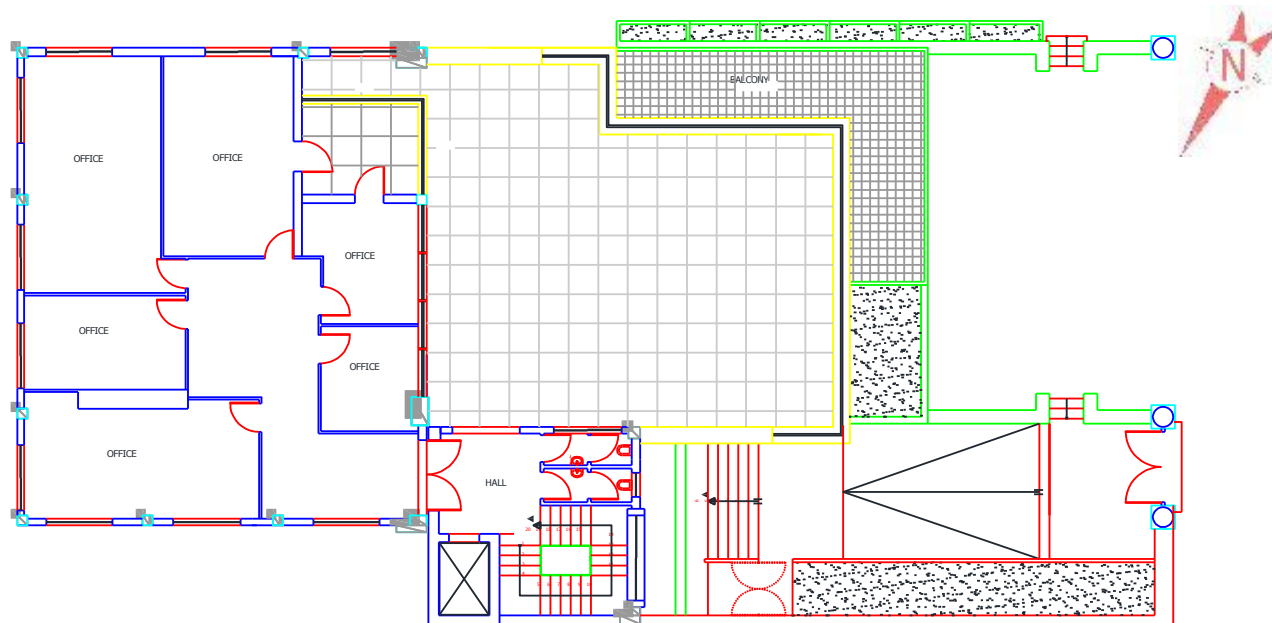


FIGURE 97: THIRD FLOOR

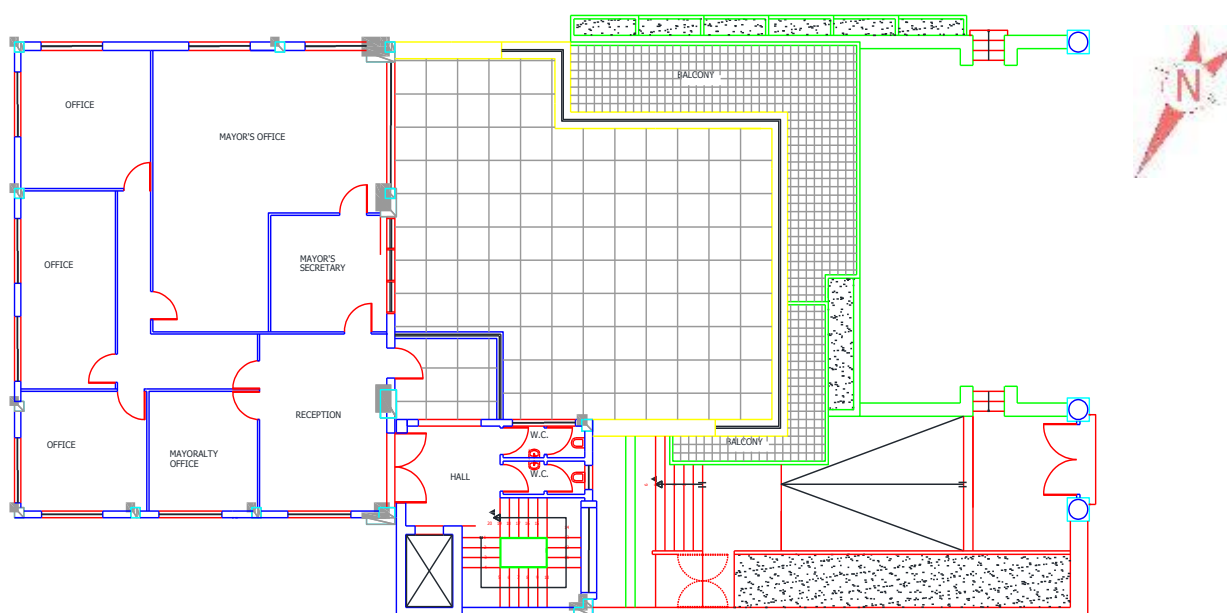
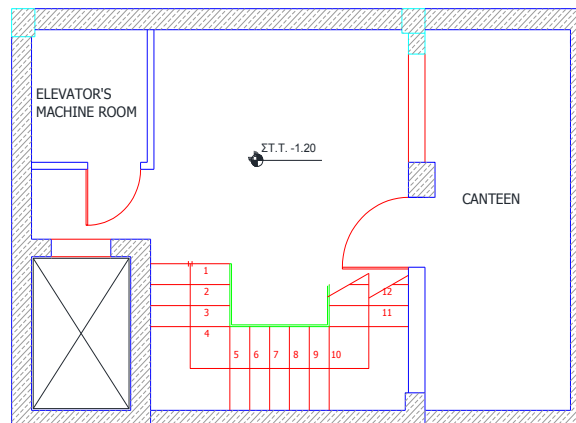
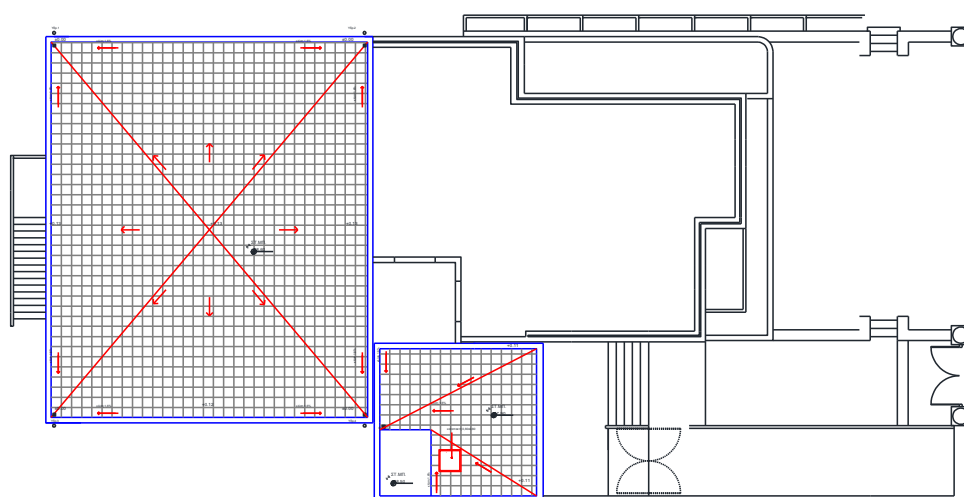


FIGURE 98: FOURTH FLOOR



**FIGURE 99: BASEMENT FLOOR PLAN**



**FIGURE 100: ROOF PLAN**

## ANNEX A-2: METEOROLOGICAL DATA FROM HELLINIKO WEATHER STATION

TABLE 89: WEATHER DATA

Month	AVERAGE MONTHLY TEMPERATURE 24H [°C]	AVERAGE MONTHLY TEMPERATURE DURING DAY [°C]	AVERAGE MAXIMUM MONTHLY TEMPERATURE [°C]	AVERAGE MINIMUM MONTHLY TEMPERATURE [°C]	ABSOLUTE MAXIMUM AVERAGE MONTHLY TEMPERATURE [°C]	ABSOLUTE MINIMUM AVERAGE MONTHLY TEMPERATURE [°C]
January	10.30	11.30	13.60	7.00	18.40	0.60
February	10.60	11.70	14.20	7.20	19.00	1.50
March	12.30	13.40	15.80	8.40	20.80	2.70
April	16.00	17.10	19.50	11.50	24.20	6.70
May	20.70	21.80	24.20	15.80	29.80	11.30
June	25.40	26.50	28.90	20.20	33.90	15.80
July	28.10	29.20	31.90	22.90	36.40	19.20
August	28.00	29.20	31.90	22.90	36.00	19.20
September	24.30	25.50	28.30	19.70	32.70	15.30
October	19.60	20.70	23.40	15.60	28.30	10.40
November	15.40	16.40	18.80	12.10	23.20	6.00
December	12.00	13.00	15.20	8.80	19.70	2.90
Month	HEATING DEGREE DAYS REFERENCE TEMPERATURE 18 °C	COOLING DEGREE HOURS REFERENCE TEMPERATURE 26 °C	MONTHLY RELATIVE HUMIDITY [%]	AVERAGE WIND SPEED [m/s]	MONTHLY TOTAL SOLAR RADIATION ON A HORIZONTAL SURFACE [kWh/(m <sup>2</sup> *mo)]	MONTHLY DIFFUSE SOLAR RADIATION ON A HORIZONTAL SURFACE [kWh/(m <sup>2</sup> *mo)]
January	239.00	-	68.80	3.90	63.00	25.10
February	207.00	-	67.60	4.00	79.00	32.20
March	177.00	-	65.80	3.80	117.90	50.30
April	60.00	-	62.50	3.00	154.30	65.70
May	-	-	58.60	3.10	195.40	81.90
June	-	794.00	52.20	3.30	214.00	85.50
July	-	1901.00	46.80	3.90	222.40	85.30
August	-	1853.00	46.70	4.00	202.70	73.70
September	-	292.00	53.50	3.60	152.60	55.50
October	-	-	62.00	3.70	109.00	40.10
November	78.00	-	68.80	3.40	70.70	26.50
December	186.00	-	70.10	3.80	55.70	22.00

## ANNEX A-3: THERMAL INSULATION STUDY U-VALUES

TABLE 90: U-VALUES OF STRUCTURAL ELEMENTS

Element	Orientation	Floor	U-Values (W/m <sup>2</sup> K)
Wall	SW	Ground	0.507
	NW		0.590
	NE		0.402
	SE		0.582
Windows			3.720
Floor			0.927
Element	Orientation	Floor	U-Values (W/m <sup>2</sup> K)
Wall	SW	1st	0.507
	NW		0.590
	NE		0.402
	SE		0.582
Windows			3.720
Floor			0.927
Roof			0.451
Element	Orientation	Floor	U-Values (W/m <sup>2</sup> K)
Wall	SW	2nd	0.523
	NW		0.523
	NE		0.500
	SE		0.512
Windows			3.490
Floor			0.927
Element	Orientation	Floor	U-Values (W/m <sup>2</sup> K)
Wall	SW	3rd	0.512
	NW		0.523
	NE		0.512
	SE		0.512
Windows			3.490
Floor			0.927
Element	Orientation	Floor	U-Values (W/m <sup>2</sup> K)
Wall	SW		0.512
	NW		0.535
	NE		0.512
	SE		0.512
Windows			3.490
Floor			0.927
Roof			0.451

## ANNEX A-4: ENERGYPLUS PARAMETERS

Below are shown the parameters which are used for the simulations (based on European standards EN ISO 13790:2008, EN 15251:2007, EN 12464.1:2002 etc. included in the Greek regulation of the energy performance of buildings KENAK) such as internal environment (temperature, ventilation, and infiltration) and internal heat loads of users and devices.

TABLE 91: INTERNAL CONDITIONS

Temperature			
	Heating	Cooling	Reference
Main rooms	20	26	KENAK
Secondary rooms	18	26	KENAK
Ventilation			
All rooms [m³/h/m²]	6		KENAK
Infiltration			
Openings [m³/(h*m) ]	1.4		KENAK
Main entrance [m³/h]	3,250		ASHRAE
AC			
	Heating	Cooling	
COP	1.7	1.5	KENAK
Schedules			
Basement - 3 <sup>rd</sup> Floor [h/d]		8	actual profile
4 <sup>th</sup> Floor [h/d]		10	actual profile

TABLE 92: INTERNAL HEAT LOADS

Internal Gains				
	People	Lighting [W/m <sup>2</sup> ]	Equipment [W/m <sup>2</sup> ]	Reference
Basement	2	6.00	35.80	actual profile
Ground Floor	26	15.68	6.40	actual profile
Ground Floor server	0	0.00	111.11	actual profile
1 <sup>st</sup> Floor	28	15.92	16.24	actual profile
1 <sup>st</sup> Floor Server	0	0.00	117.19	actual profile
2 <sup>nd</sup> Floor	17	11.16	10.04	actual profile
3 <sup>rd</sup> Floor	11	15.62	10.60	actual profile
4 <sup>th</sup> Floor	9	15.41	6.68	actual profile

## ANNEX A-5: ENERGYPLUS MATERIALS

TABLE 93: MATERIALS

Ground Floor				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Marble	0.02	3.489	2,600	840
Mortar	0.02	0.872	1,500	1,000
Gravel-concrete	0.06	0.640	1,900	1,000
Insulation_1	0.04	0.040	35	1,210
Slab_1	0.15	1.511	2,400	840
1 <sup>st</sup> Floor Roof				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Plaster	0.02	0.872	1,900	1,090
Slab_2	0.14	2.035	2,500	840
Perlobeton	0.04	0.197	803	900
Insulation_2	0.07	0.040	30	1210
Gravel-beton	0.03	0.814	1,600	1,000
Floor over basement				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Marble	0.02	3.489	2,600	840
Mortar	0.02	0.872	1,500	1,000
Perl-concrete	0.1	0.162	800	900
Slab_2	0.14	2.035	2,400	840
Plaster	0.02	0.872	1,900	1,090
External Wall Ground & 1 <sup>st</sup> floor				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Plaster	0.02	0.872	1,900	1,090
Brick	0.09	0.523	1,200	840
Insulation_3	0.07	0.029	25	1,210
Brick	0.09	0.523	1,200	840
Plaster	0.02	0.872	1,900	1,090

External Wall 2 <sup>nd</sup> ,3 <sup>rd</sup> ,4 <sup>th</sup> floor				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Plaster	0.02	0.872	1,900	1,090
Brick	0.09	0.523	1,200	840
Insulation_3	0.07	0.029	25	1,210
Brick	0.09	0.523	1,200	840
Plaster	0.02	0.872	1,900	1,090
2 <sup>nd</sup> ,3 <sup>rd</sup> ,4 <sup>th</sup> Floor				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Marble	0.02	3.489	2,600	840
Mortar	0.02	0.872	1,500	1,000
Foam_concret_1)	0.05	0.128	600	900
Slab_1	0.15	2.035	2,400	840
Plaster	0.02	0.872	1,900	1,090
Roof				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Plaster	0.02	0.872	1,900	1,090
Slab_3	0.16	2.035	2,400	840
Foam_concrete_2	0.08	0.128	600	900
Waterproofing)	0.01	0.174	1,050	200
Tile)	0.07	1.047	2,000	590
Floor over Pilotis				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Marble	0.02	3.489	2,600	840
Mortar	0.02	0.872	1,500	1,000
Gravel-concrete	0.06	0.640	1,900	900
Slab_1	0.15	2.035	2,400	840
Roofmate	0.04	0.023	35	1,210
Plaster	0.02	0.872	1,900	1,090



## ANNEX A-6: SHADING ANALYSIS

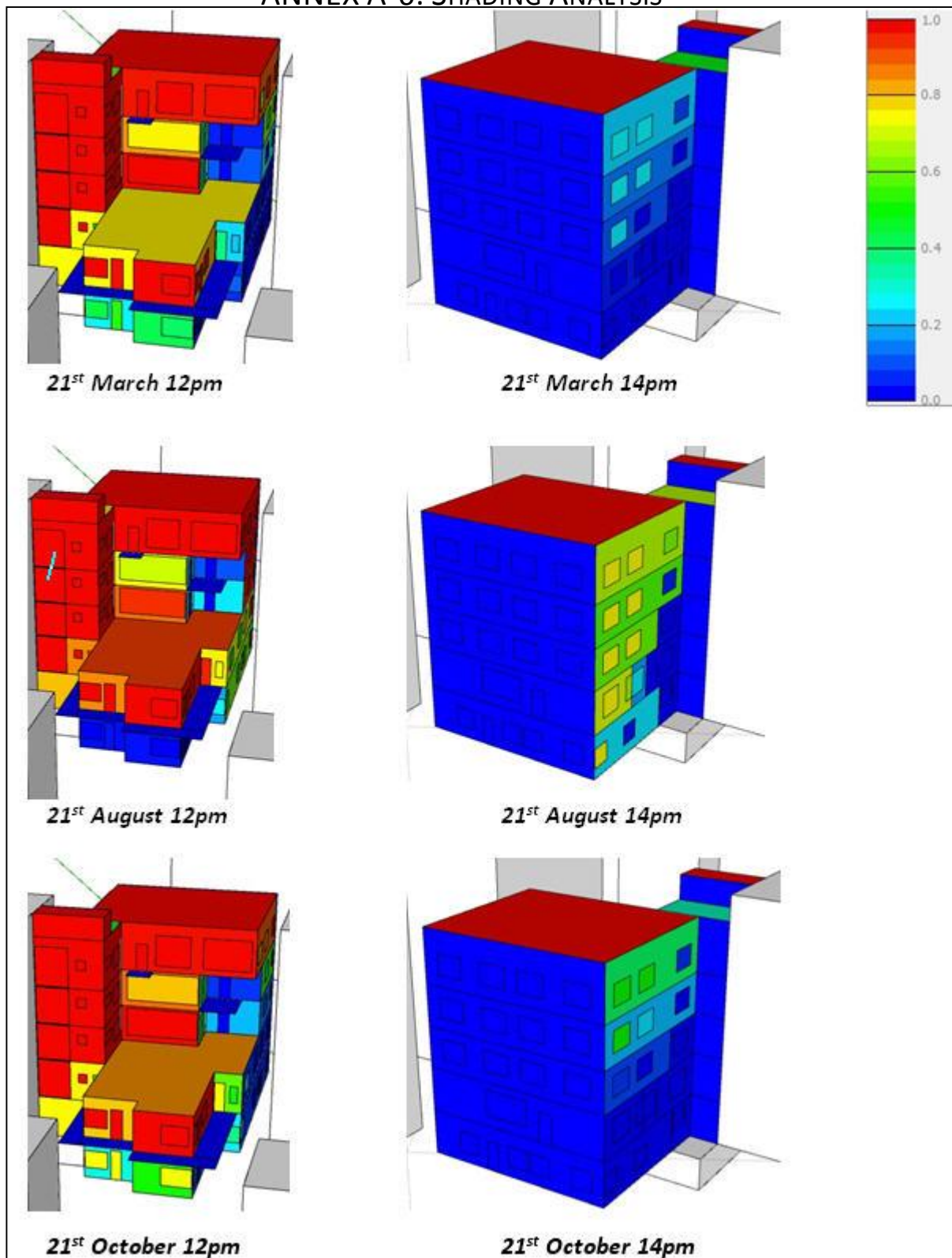


FIGURE 101: SAMPLE OF THE SHADING ANALYSIS WITH ENERGYPLUS

## ANNEX A-7: PVGIS ESTIMATION OF PV SYSTEM POWER PRODUCTION

### PVGIS estimates of solar electricity generation

Location: 37°54'40" North, 23°42'46" East, Elevation: 8 m a.s.l.,

Solar radiation database used: PVGIS-classic

Nominal power of the PV system: 15.3 kW (crystalline silicon)

Estimated losses due to temperature and low irradiance: 10.1% (using local ambient temperature)

Estimated loss due to angular reflectance effects: 2.8%

Other losses (cables, inverter etc.): 10.0%

Combined PV system losses: 21.4%

Fixed system: inclination=25°, orientation=30°				
Month	$E_d$	$E_m$	$H_d$	$H_m$
Jan	35.80	1110	2.82	87.5
Feb	41.00	1150	3.26	91.4
Mar	54.30	1680	4.40	136
Apr	66.90	2010	5.51	165
May	73.60	2280	6.17	191
Jun	79.40	2380	6.79	204
Jul	78.10	2420	6.78	210
Aug	73.70	2280	6.41	199
Sep	67.80	2030	5.78	173
Oct	50.60	1570	4.20	130
Nov	35.00	1050	2.83	85.0
Dec	30.70	950	2.44	75.5
Yearly average	57.3	1740	4.79	146
Total for year		20900		1750

$E_d$ : Average daily electricity production from the given system (kWh)

$E_m$ : Average monthly electricity production from the given system (kWh)

$H_d$ : Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m<sup>2</sup>)

$H_m$ : Average sum of global irradiation per square meter received by the modules of the given system (kWh/m<sup>2</sup>)

PVGIS © European Communities, 2001-2012

FIGURE 102: PVGIS PV ESTIMATION

## ANNEX A-8: RENOVATION OPTION MATRIX BY SINLOC

TABLE 94: ECONOMIC EVALUATION OF INTERVENTIONS

				Work timing						CAPEX						
				Installed power or size of intervention	Construction Period	Compulsory connection with other technologies/ layers	Specify which technologies are needed to realize this layer	Specify which technologies can be realized only after this layer	Investment cost			Investment payback period (preliminary)	Lifetime (year of replacement - revamping)	Energy consumption (after each single energy renovation option)		
Renovation options	Types	Technologies / Layers	Code	Unit of measure	Value	Months	Yes/No	Code/codes (ascending order)	Code/codes (ascending order)	Unit of measure	Unit cost	Value	Years	Years	Source 1	Unit of measure
HVAC	Replacement of heating/cooling plants	VRV	1	kW	125	1.5	No		9	€/kW	435	54414	10.7	25	Electricity	kWh
	Ventilation system	Heat recovery	2	m3/h	2500	0.10	Yes	1	9	€/m/h	2.56	6400	9.5	25	Electricity	kWh
	Night Ventilation		3	ACH	15	0.35	No		9	€/ACH	300	4500	3.9	25	Electricity	kWh
Casing Building skin	External insulation	EPS or MINERAL WOOL	4	square meter	1417	1.0	No			€/sq.m	48	67890	63.5	50	Electricity	kWh
	Shading elements	Mobile	5	square meter	117	0.5	No			€/sq.m	173.6	20325	15.6	25	Electricity	kWh
Windows	Windows	Low-e Thermo Break	6	square meter	286	1.5	No			€/sq.m	157.3	45000	100.6	50	Electricity	kWh
Lighting systems (internal)	Replacement of lamps (and luminaries, ballast)	LED	7	watt	9190	0.5	No		9	€/watt	1.67	15370	6.1	10	Electricity	kWh
Renewable energy	Solar	Photovoltaic panels	8	kW	15.26	0.25	No			€/kW	1400	20900	8.5	25	Electricity	kWh
Control systems	BMS	BMS	9	signal	150	0.25	Yes	1,2,3,7		€/signal	113	17000		25	Electricity	kWh
Passive systems	Solar gains circulation	Vent openings	10	no of openings	4	0.2	No			€/no	250	1000	34.7	50	-	-

				OPEX									SAVINGS							
				Energy consumption (after each single energy renovation option)	Labor/Management and ordinary maintenance contracts			Extraordinary maintenance				Potential energy savings expected from the intervention				Potential savings from maintenance (post intervention)		Potential savings of CO2		
						Cost of components	Cost of personnel	Total	Frequency	Cost of intervention	Cost of personnel	Total	Electric energy consumption							
Renovation options	Types	Technologies / Layers	Code	Consumption /year	€/year	€/year	€/year	€/year	years	€	€	€/year	%, first year	kWhe/year, first year	%, last year	kWhe/year, last year	%	€/year	%	Equivalent tons/year
HVAC	Replacement of heating/ cooling plants	VRV	1	68899	8130	250	750	1000	7	2000	1000	429 €	38%	43066	32%	35888	10	517	38	42.59
	Ventilation system	Heat recovery	2	106242	12537		50	50					5%	5723	4%	4769	10	69	5	5.66
	Night Ventilation		3	102256	12066		100	100	10	450	50	50	9%	9709	9%	9709	10	117	9	9.60
Casing Building skin	External insulation	EPS or MINERAL WOOL	4	102911	12143				15	6900	6900	920	8%	9054	8%	9054	0	0	8	8.95
	Shading elements	Mobile	5	100924	11909				7	300	200	71	10%	11041	10%	11041	0	0	10	10.92
Windows	Windows	Low-e Thermo Break	6	108176	12765				15	1000	500	100	3%	3789	3%	3789	0	0	3	3.75
Lighting systems (internal)	Replacement of lamps (and luminaries, ballast)	LED	7	90447	10673		200	200					19%	21518	16%	17932	10	258	19	21.28
Renewable energy	Solar	Photovoltaic panels	8	91065	10746		200	200	7	1250	250	214	19%	20900	16%	17417	10	251	19	20.67
Control systems	BMS	BMS	9	79876	9425		500	500	2	150	50	100	29%	32089	29%	32089	20	770	29	31.74
Passive systems	Solar gains circulation	Vent openings	10	111721	13183		50	50					0.2%	244	0.2%	244	0	0	0.2%	0.24

## ANNEX B – ENVIRONMENTAL SERVICES OFFICES

### ANNEX B-1: BUILDING DRAWINGS

Below are the rest drawings of the building.

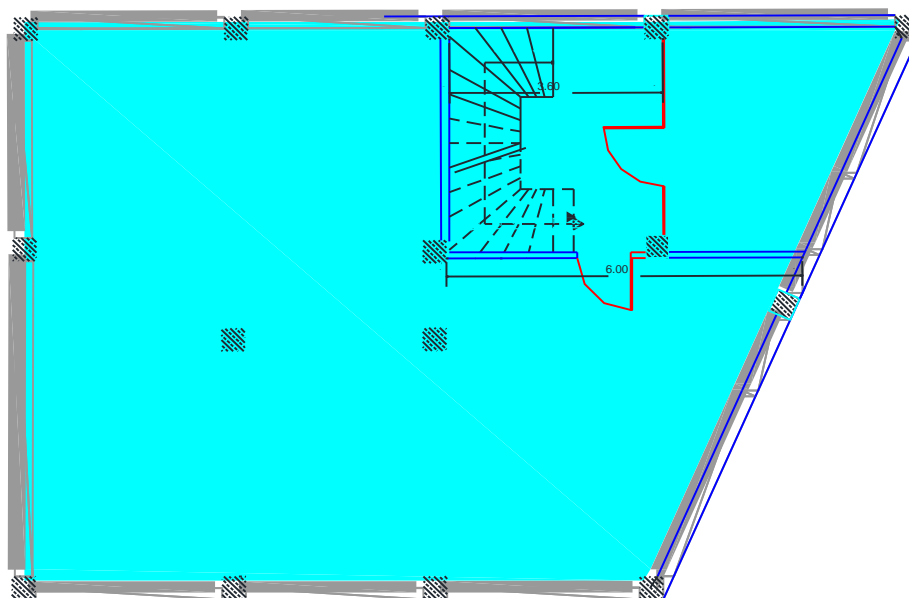


FIGURE 103: BASEMENT FLOOR PLAN

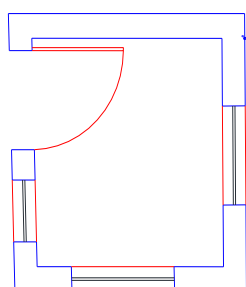


FIGURE 104: BUILDING 2

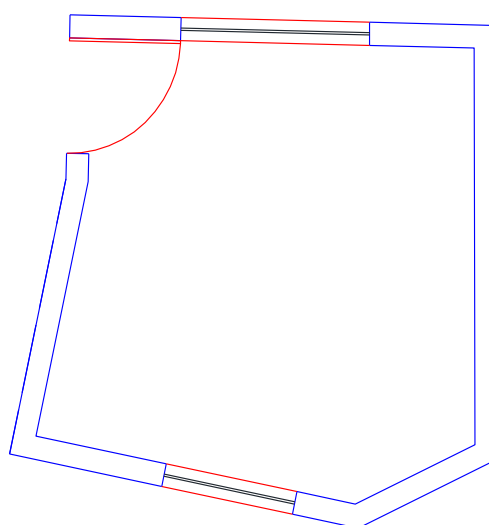


FIGURE 105: BUILDING 1

## ANNEX B-2: THERMAL INSULATION STUDY U-VALUES

TABLE 95: U-VALUES OF STRUCTURAL ELEMENTS

Element	Orientation	Floor	U-Values (W/m <sup>2</sup> K)
Wall	SW	Ground	0.587
	NW		0.587
	NE		0.587
	SE		0.587
Windows			5.820
Floor			0.627
Roof			0.450



## ANNEX B-3: ENERGYPLUS PARAMETERS

Below are shown the parameters which are used for the simulations (based on Euro-pean standards EN ISO 13790:2008, EN 15251:2007, EN 12464.1:2002 etc. included in the Greek regulation of the energy performance of buildings KENAK) such as internal environment (temperature, ventilation, and infiltration) and internal heat loads of users and devices.

TABLE 96: INTERNAL CONDITIONS

Temperature			
	Heating	Cooling	Reference
Main rooms	20	26	KENAK
Secondary rooms	18	26	KENAK
Ventilation			
All rooms [m³/h/m²]	6		KENAK
Infiltration			
Openings [m³/(h*m) ]	1.4		KENAK
Main entrance [m³/h]	3,250		ASHRAE
AC			
	Heating	Cooling	
COP	1.7	1.5	KENAK
Schedules			
Ground Floor- Building 1 [h/d]		8	actual profile
Building 2 [h/d]		24	actual profile

TABLE 97: INTERNAL HEAT LOADS

Internal Gains				
	People	Lighting [W/m <sup>2</sup> ]	Equipment [W/m <sup>2</sup> ]	Reference
Office_1	18	2,178	1,141	actual profile
Entrance	6	174	0	actual profile
WC	5	552	0	actual profile
CAFE	7	410	2,239	actual profile
Office_2	4	368	175	actual profile
Basement	0	72	0	actual profile
Building 1	1	72	150	actual profile
Building 2	1	40	0	actual profile



## ANNEX B-4: ENERGYPLUS MATERIALS

TABLE 98: MATERIALS

Ground Floor				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
gravel	0.20	3.480	1,920	900
3A	0.05	1.400	1,920	900
beton	0.12	1.500	2,400	840
cement	0.020	1.400	1,500	1,000
plastic	0.002	0.400	1,500	1,200
glass fiber	0.05	0.400	2,500	800
Roof				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
plaster	0.02	0.872	1,900	1,090
slab	0.15	2.035	2,400	840
insulation	0.06	0.040	35	1,210
cement_incl	0.1	0.290	800	1,000
waterproof	0.01	0.174	1,050	200
Gravel_2	0.07	0.640	1,500	900
External Wall				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
plaster	0.02	0.872	1,900	1,090
brick	0.09	0.523	1,200	840
Insulation_2	0.05	0.040	25	1,210
brick	0.09	0.523	1,200	840
plaster	0.02	0.872	1,900	1,090

## ANNEX B-5: PVGIS ESTIMATION OF PV SYSTEM POWER PRODUCTION

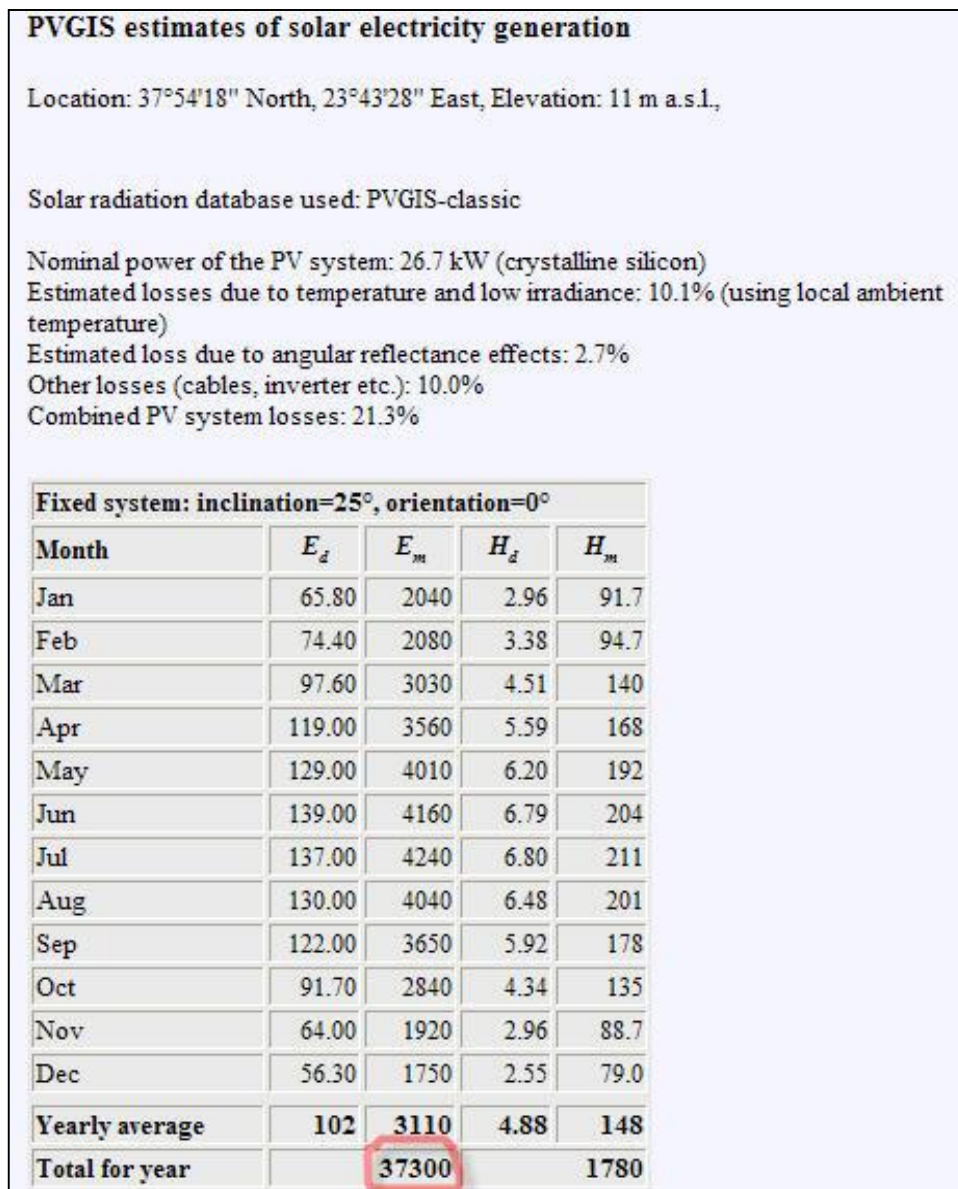


FIGURE 106: PVGIS PV ESTIMATION

## ANNEX B-6: RENOVATION OPTION MATRIX BY SINLOC

TABLE 99: ECONOMIC EVALUATION OF INTERVENTIONS

				Work timing						CAPEX						
				Installed power or size of intervention	Construction Period	Compulsory connection with other technologies/ layers	Specify which technologies are needed to realize this layer	Specify which technologies can be realized only after this layer	Investment cost		Investment payback period (preliminary)	Lifetime (year of replacement - revamping)	Energy consumption (after each single energy renovation option)			
Renovation options	Types	Technologies / Layers	Code	Unit of measure	Value	Months	Yes/No	Code/codes (ascending order)	Code/codes (ascending order)	Unit of measure	Unit cost	Value	Years	Years	Source 1	Unit of measure
HVAC	Replacement of heating/cooling plants	VRV	1	kW	37,5	1,5	No		14	€/kW	467,20	17520	11,2	25	Electricity	kWh
			2													
			3													
Casing Building skin	External insulation	[ EPS or MINERAL WOOL ]	4	square meter	700	1,0	No			€/sq.m	31,01	21707	176,9	50	Electricity	kWh
			5													
			6													
Windows	Windows	Low-e Thermo Break	7	square meter	58	1,5	No			€/sq.m	172,41	10000	38,9	50	Electricity	kWh
Lighting systems (internal)	Replacement of lamps (and luminaries, ballast)	LED	8													
			9	watt	1870	0,5	No		14	€/watt	1,76	3285	6,7	10	Electricity	kWh
			10													
Renewable energy	Solar	Photovoltaic panels	11													
			12	kW	26,7	0,25	No			€/kW	1400,00	37380	10,2	25	Electricity	kWh
Control systems	BMS	BMS	13													
			14	signal	48	0,25	Yes	1,9		€/signal	183,33	8800	8,3	25	Electricity	kWh
Ventilation systems	Night Ventilation	fun/damper	15	ACH	15	0,25	No		14	€/ACH	210,00	3150	39,1	25	Electricity	kWh

				OPEX									SAVINGS							
				Energy consumption (after each single energy renovation option)	Labor/Management and ordinary maintenance contracts			Extraordinary maintenance				Potential energy savings expected from the intervention				Potential savings from maintenance (post intervention)		Potential savings of CO2		
						Cost of components	Cost of personnel	Total	Frequency	Cost of intervention	Cost of personnel	Total	Electric energy consumption							
Renovation options	Types	Technologies / Layers	Code	Consumption /year	€/year	€/year	€/year	€/year	years	€	€	€/year	%, first year	kWhe/year, first year	%, last year	kWhe/year, last year	%	€/year	%	Equivalent tons/year
HVAC	Replacement of heating/cooling plants	VRV	1	17218	3099	100	200	300	7	600	400	143	43%	12942	36%	10785	10	100	43%	12,80
			2																	
			3																	
Casing Building skin	External insulation	[ EPS or MINERAL WOOL ]	4	29146	5246								3%	1014	3%	1014	0	0	3%	1,00
			5																	
			6																	
Windows	Windows	Low-e Thermo Break	7	28034	5046				15	200	100	20	7%	2126	7%	2126	0	0	7%	2,10
			8																	
Lighting systems (internal)	Replacement of lamps (and luminaries, ballast)	LED	9	26080	4694		100	100					14%	4080	14%	4080	0	0	14%	4,04
			10																	
			11																	
Renewable energy	Solar	Photovoltaic panels	12	0	0		250	250	7	1500	300	257	100%	30160	83%	25133	0	0	100%	29,83
Control systems	BMS	BMS	13																	
			14	21405	3853		250	250	2	150	50	100	29%	8755	29%	8755	0	0	29%	8,66
Ventilation systems	Night Ventilation	fun/damper	15																	
			16																	
			17	29494	5309		100	100	10	450	50	50	2%	666	2%	666	0	0	2%	0,66

## ANNEX C – MUNICIPAL LIBRARY

### ANNEX C-1: BUILDING DRAWINGS

Below are the rest drawings of the building.

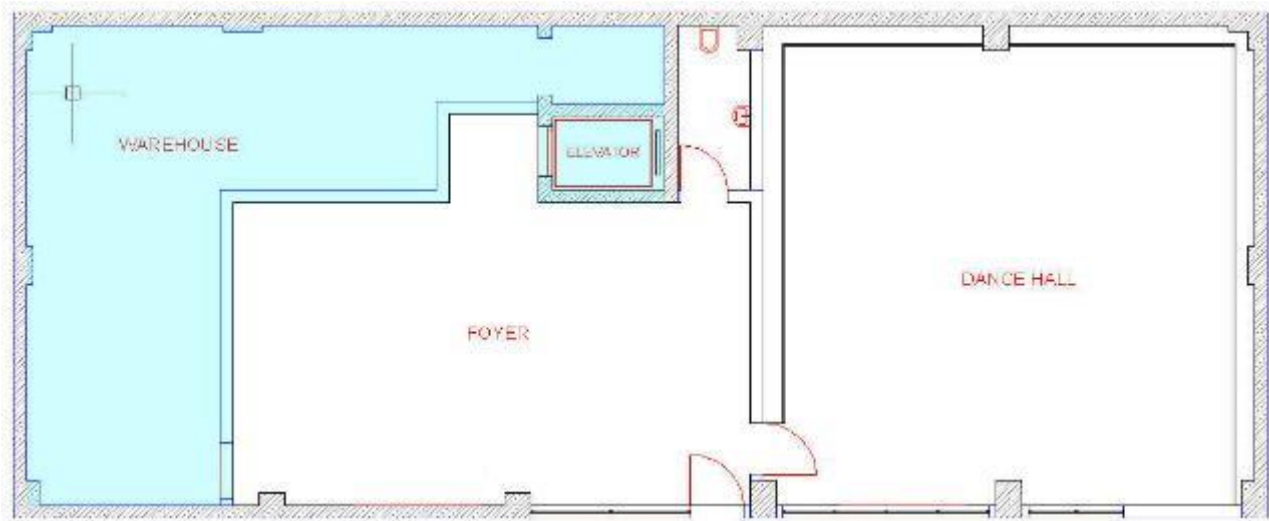


FIGURE 107: BASEMENT

## ANNEX C-2: THERMAL INSULATION STUDY U-VALUES

TABLE 100: U-VALUES OF STRUCTURAL ELEMENTS

Element	Orientation	Floor	U-Values (W/m <sup>2</sup> K)
Wall	SW	Ground	0.640
	NW		0.616
	NE		0.605
	SE		0.640
	SW	First	0.640
	NW		0.616
	NE		0.605
	SE		0.640
	SW	Second	0.640
	NW		0.616
	NE		0.605
	SE		0.640
	SW	Basement	0.651
	NW		0.651
	NE		0.651
	SE		0.651
Windows			5.820
Floor			0.570

## ANNEX C-3: ENERGYPLUS PARAMETERS

Below are shown the parameters which are used for the simulations (based on Euro-pean standards EN ISO 13790:2008, EN 15251:2007, EN 12464.1:2002 etc. included in the Greek regulation of the energy performance of buildings KENAK) such as internal environment (temperature, ventilation, and infiltration) and internal heat loads of users and devices.

TABLE 101: INTERNAL CONDITIONS

Temperature			
	Heating	Cooling	Reference
Main rooms	20	26	KENAK
Secondary rooms	22	24	KENAK
Ventilation			
All rooms [m³/h/m²]	6		KENAK
Infiltration			
Openings [m³/(h*m) ]	1.4		KENAK
Main entrance [m³/h]	3,250		ASHRAE
AC			
	Heating	Cooling	
COP	1.7	1.5	KENAK
Schedules			
Ground Floor, [h/d]		11	actual profile
Basement, 1st Floor [h/d]		3	actual profile
2nd Floor [h/d]		8	actual profile



TABLE 102: INTERNAL HEAT LOADS

Internal Gains				
	People	Lighting [W/m <sup>2</sup> ]	Equipment [W/m <sup>2</sup> ]	Reference
WC Basement	0	17.0	0	actual profile
Library Basement	30	17.0	50	actual profile
Entrance Ground	0	18.6	0	actual profile
Library Ground	12	18.6	425	actual profile
WC 1st Floor	0	8.4	0	actual profile
Entrance 1st Floor	0	8.4	0	actual profile
Library 1st Floor	20	8.4	50	actual profile
WC 2nd Floor	0	14.0	0	actual profile
Entrance 2nd Floor	0	14.0	0	actual profile
Library 2nd Floor	10	14.0	2,145	actual profile

## ANNEX C-4: ENERGYPLUS MATERIALS

TABLE 103: MATERIALS

Ground Floor				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Marbel_1	0.02	3.489	2,700	840
Plaster	0.02	0.872	1,900	1,090
Insulation_1	0.06	0.040	35	1,210
Beton arme	0.15	2.035	2,400	840
Plaster	0.02	0.872	1,900	1,090
Roof				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Marbel	0.03	3.489	2,700	840
Plaster	0.02	0.872	1,900	1,090
Concrete	0.04	0.349	1,000	1,000
Insulation_2	0.08	0.040	35	1210
Beton arme	0.15	2.035	2,400	840
Plaster	0.02	0.872	1,900	1,090
External Wall				
	Thickness (m)	Conductivity (W/m-K)	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg-K)
Plaster	0.02	0.872	1,900	1090
Brick	0.06	0.523	1,200	840
Insulation_3	0.05	0.040	20	1,210
Brick	0.06	0.523	1,200	840
Plaster	0.02	0.872	1,900	1,090

## ANNEX C-5: PVGIS ESTIMATION OF PV SYSTEM POWER PRODUCTION

### PVGIS estimates of solar electricity generation

Location: 37°55'25" North, 23°44'25" East, Elevation: 78 m a.s.l.,

Solar radiation database used: PVGIS-classic

Nominal power of the PV system: 5.7 kW (crystalline silicon)

Estimated losses due to temperature and low irradiance: 10.1% (using local ambient temperature)

Estimated loss due to angular reflectance effects: 2.7%

Other losses (cables, inverter etc.): 10.0%

Combined PV system losses: 21.3%

Fixed system: inclination=25°, orientation=0°				
Month	$E_d$	$E_m$	$H_d$	$H_m$
Jan	14.20	440	2.96	91.6
Feb	16.10	450	3.39	95.0
Mar	21.00	652	4.52	140
Apr	25.60	769	5.61	168
May	27.80	863	6.22	193
Jun	29.80	895	6.80	204
Jul	29.40	912	6.82	211
Aug	28.10	872	6.52	202
Sep	26.20	786	5.94	178
Oct	19.70	612	4.34	135
Nov	13.80	415	2.97	89.1
Dec	12.20	378	2.56	79.3
Yearly average	22.0	670	4.89	149
Total for year		8040		1790

FIGURE 108: PVGIS PV ESTIMATION

## ANNEX C-6: RENOVATION OPTION MATRIX BY SINLOC

TABLE 104: ECONOMIC EVALUATION OF INTERVENTIONS

				Work timing						CAPEX						
				Installed power or size of intervention	Construction Period	Compulsory connection with other technologies/ layers	Specify which technologies are needed to realize this layer	Specify which technologies can be realized only after this layer	Investment cost		Investment payback period (preliminary)	Lifetime (year of replacement - revamping)	Energy consumption (after each single energy renovation option)			
Renovation options	Types	Technologies / Layers	Code	Unit of measure	Value	Months	Yes/No	Code/codes (ascending order)	Code/codes (ascending order)	Unit of measure	Unit cost	Value	Years	Years	Source 1	Unit of measure
HVAC	Replacement of cooling system	A/C splits	1	kW	41,5	1,5	No		14	€/kW	325,30	13500	6,5	25	Electricity	kWh
	Replacement of heating system	Pellet boiler (central heating system)	2	kW	75	0,25	No			€/kW	24,67	1850	2,5	25	Electricity	kWh
			3													
Casing Building skin	External insulation		4	square meter	725	1,0	No			€/sq.m	42,62	30900	3012	50	Electricity	kWh
			5													
Windows	Windows	Low-e Thermo Break	6													
			7	square meter	258	1,5	No			€/sq.m	157,56	40650	-	50	Electricity	kWh
Lighting systems (internal)	Replacement of lamps (a	LED	8													
			9	watt	1536	0,5	No		14	€/watt	1,40	2150	2,4	10	Electricity	kWh
			10													
Renewable energy	Solar	Photovoltaic panels	11													
			12	kW	5,76	0,25	No			€/watt	1388,89	8000	5,8	25	Electricity	kWh
Control systems	Power meter/Thermostats/Lux sensors	Power meter/Thermostats/Lux sensors	13													
			14	Control Points	26	0,25	Yes	1,2,9		€/C.P.	115,77	3010	0,7	25	Electricity	kWh
Ventilation systems	Night Ventilation	fun/damper	16													
			17	ACH	15	0,25	No		14	€/ACH	266,67	4000	6,4	25	Electricity	kWh

				OPEX													SAVINGS							
				Energy consumption (after each single energy renovation option)					Labor/Management and ordinary maintenance contracts			Extraordinary maintenance					Potential energy savings expected from the intervention				Potential savings from maintenance (post intervention)		Potential savings of CO2	
Renovation options	Types	Technologies / Layers	Code	Consumption /year	€/year	Source 2	Unit of measure	Consumption /year	€/year	€/year	€/year	years	€	€	€/year	Electric energy consumption				%	€/year	%	Equivalent tons/year	
																% first year	kWhe/year, first year	% last year	kWhe/year, last year					
HVAC	Replacement of cooling system Replacement of heating system	A/C splits Pellet boiler (central heating system)	1	29962	5393	pellet	tons	4,223	1098	0	200	200	7	100	100	200	29%	12174	24%	10145	0	0	29%	12,04
			2	31396	5651					0	100	100	5	100	100	200	-101%	0	-84%	0	0	0	26%	10,67
			3																					
Casing Building skin	External insulation		4	42076	7574												0,1%	60	0,1%	60	0	0	0,1%	0,06
			5																					
			6																					
Windows	Windows	Low-e Thermo Break	7	42628	7673							15	500	250	50	-1%	-492	-1%	-492	0	0	0%	0,00	
			8																					
Lighting systems (internal)	Replacement of lamps (and luminaries, ballast)	LED	9	36913	6644						200	200					12%	5223	10%	4353	0	0	12%	5,17
			10																					
			11																					
Renewable energy	Solar	Photovoltaic panels	12	34095	6137						200	200	7	550	150	100	19%	8041	16%	6701	0	0	19%	7,95
			13																					
Control systems	Power meter/Thermostats/Lux sensors	Power meter/Thermostats/Lux sensors	14	15145	2726							0	5	400	100	100	64%	26991	64%	26991	0	0	64%	26,69
			16																					
Ventilation systems	Night Ventilation	fun/damper	17	38462	6923						100	100	10	450	50	50	9%	3674	9%	3674	0	0	9%	3,63



**ENEA – Italian National Agency for New Technologies, Energy and Sustainable Economic Development (IT)**



**Municipality of Messina (IT)**



**Municipality of Erreterria (ES)**



**Municipality of Coimbra (PT)**



**Municipality of Alimos (EL)**



**ISR – University of Coimbra (PT)**



**SINLOC - Sistema Iniziative Locali Spa (IT)**



**ETVA VI.PE. S.A. (EL)**



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**Danish Building Research Institute, Aalborg University  
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