Evaluation of Energy Upgrade Measures and Connection of Renewable Energy Sources Using Software Tools: Case Study of an Academic Library Building in Larissa, Greece

Giwrgos S. Gkarmpounis, Aikaterini G. Rokkou, Marios N. Moschakis

***Abstract*—**Increased energy consumption in the academic buildings, creates the need to implement energy saving measures and to take advantage of the renewable energy sources to cover the electrical needs of those buildings. An Academic Library will be used as a case study. With the aid of RETScreen software that takes into account the energy consumptions and characteristics of the Library Building, it is proved that measures such as the replacement of fluorescent lights with led lights, the installation of outdoor shading, the replacement of the openings and Building Management System installation, provide a high level of energy savings. Moreover, given the available space of the building and the climatic data, the installation of a photovoltaic system of 100 kW can also cover a serious amount of the building energy consumption, unlike a wind system that seems uncompromising. Lastly, HOMER software is used to compare the use of a photovoltaic system against a wind system in order to verify the results that came up from the RETScreen software concerning the renewable energy sources.

***Keywords*—**Energy saving measures, homer software, renewable energy sources, RETScreen software, energy efficiency and quality.

I. Introduction

THE key objective of Greece's energy policy, following the oil crises of the 1970s, was to reduce dependence on oil by exploiting domestic lignite and hydroelectric power in electricity generation and introducing natural gas into the energy mix..

In April 1998, the Kyoto Protocol was signed by Greece alongside the other European Union (EU) member states and the European Commission. The Protocol was ratified in May 2002 by all member states, whereby came up the obligation to reduce emissions of gaseous pollutants (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, fully fluorinated hydrocarbons and sulfur hexafluoride) by 8% in the period 2008-2012, compared to base year (1990) emissions. Greece, in line with that decision, committed itself to limit its emissions increase to 25% in 2008-2012 in order to contribute to the EU's shared target of 8% reduction in its emissions over the same period [1].

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The above objective has not been achieved and a new target has been set by Europe in accordance with the Copenhagen Conference which includes 30% reduction in greenhouse gas emissions by 2020, 20% energy savings, 20% of energy consumed by Renewable Energy Sources (RES), biofuel transport fuel content of 10% and maintaining maximum average global warming below 2 °C [2].

Greece has a high RES potential in all sectors of final consumption as well as electricity generation. In the last few years, and especially after 2006, efforts are being made to exploit the potential of power generation in the most optimal way, by adopting a series of changes in the institutional framework of licensing and use of RES systems, but also by using the necessary financial tools. The average growth rate of wind and small hydroelectric systems is around 15%, while the maximum and minimum growth rates occur before and after the changes in the institutional framework and the respective aid mechanisms. For photovoltaics, there has been a strong growth since 2008, when difficulties and delays have been encountered with regard to their licensing, and new development programs have also been presented [3].

II. Academic Library Building in Larissa, Greece

Energy consumption in the building sector for heating, cooling, lighting and hot water accounts for around 40% of total energy consumption in Europe, as in the case in Greece. The energy used in buildings is in the form of electricity, heating oil and natural gas. In two ways, energy is consumed in buildings. The first concerns the energy consumption for space heating in winter, in the form of combustion of oil or gas in the boiler burner and the second the consumption of electricity for cooling or heating the building with air conditioners, for its lighting and for the operation of electrical appliances. Thus, the energy status of a building is determined on the basis of final actual thermal and electrical energy [2].

The Academic Library building in Larissa, which is being studied, consists of three levels (the basement-1st level, the ground -2nd level and the 3rd level) and occupies a total area of 277.,66 m^2. It belongs to the tertiary sector, in climatic zone C and its use is treated like offices and shops. The building is shown at Fig. 1.

Fig. 1 Academic library building in Larissa, Greece

For buildings with features similar to the one in the building under study, the most energy-efficient measure [9], [12] is the installation of the Building Management System (BMS). BMS is a control system installed in buildings, the purpose of which is to supervise and control the building's electromechanical installations, such as cooling, heating, ventilation and lighting. It is usually installed in large buildings and some of its main functions are controlling the temperature and humidity of the rooms, managing the cooling and heating systems and controlling the levels of carbon dioxide. The benefits of implementing such a system are economic (fuel and cost of electromechanical installations reduction), energy (energy savings and thermal/optical comfort), environmental (reduction of pollutants, greenhouse effect) and social (improving quality of life).

The second best energy saving measure is replacing lamps with high energy efficient lamps, such as led lamps. Led lamps achieve the same light output with a power consumption of ten times less than incandescent lamps or three - four times lower than energy saving lamps because the light that they emit is directional and totally focused, and consumes less power, while not emitting high temperatures. Also, their life spans are much longer.

In addition, energy savings in tertiary buildings and therefore in the building under consideration can result from the regular maintenance of central heating (maintenance of good efficiency), the application of external thermal insulation and thermal insulation of the roof (reduction of thermal losses and cooling loads), replacing double-glazed windows and placing external shading (which reduces the cooling required in the summer months).

III. Software Results

Indeed, analyzing the energy saving measures with the help of the RETScreen software [10]. It is concluded that the first solution to be applied to the library building with the greatest potential for saving energy is the replacement of lamps with led lamps. The second proposed measure is to place external shading for the summer. Also, replacing the building's openings (windows) is an energy saving measure with satisfactory results. However, it is an expensive investment. Finally, installing a BMS system offers the possibility of a very high potential for energy savings. Furthermore, the possibility of covering part of the electrical needs of the library building by means of photovoltaic (PV) and/or wind turbines is being considered [7], [8], [13]. In particular, two scenarios are examined using the RETScreen software. In the first case, the installation of a photovoltaic array and/or a wind turbine with a power of 50 kW each and in the second case the installation of a photovoltaic array and/or a wind turbine of 100 kW each are considered.

The selection of the specific sizes of the power of RES is based on the available free space of the building for the installation of the photovoltaic, which is the roof of the building. Only the space available for photovoltaics is being considered, as it is documented in this paper that the installation of wind turbines is not indicated in this building.

The aim is also to meet the needs for energy other than the energy required for heating. As in this case, the existing central heating system should be replaced, with one that consumes electricity instead of natural gas, which requires a very large initial cost.

After an economic analysis of the scenarios, as well as an environmental assessment of the reduction of greenhouse gases, the most advantageous solution is the installation of a photovoltaic array of 100 kW power, while the installation of a wind turbine due to the low wind potential in the area is not appropriate. By comparing the results with the results extracted from the HOMER software [11], the same conclusions are drawn.

IV. Data Collected

The heating-cooling-ventilation system of the Academic Library Building in Larissa, as well as its electrical installations, were studied, in order to calculate the total energy needs, the coverage of which - with the use of photovoltaic and/or wind turbines - is the subject of this study.

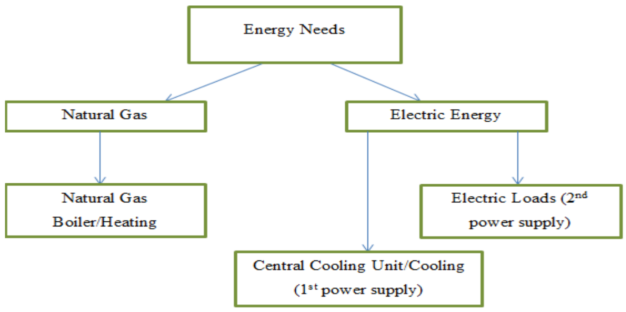


Fig. 2 Energy needs of the building

Consumption data used have been exported from gas accounts exclusively for the library's natural gas meter and from an electricity meter, which is located in the general building table and therefore covers all electrical uses (1st power supply) other than the central cooling unit, which is fed by a different supply (2nd power supply) and is studied separately. Fig. 2 shows the forms of energy that are consumed in the building.

According to the data collected, the consumption of natural gas is shown on Fig. 3 and in detail on Table I.

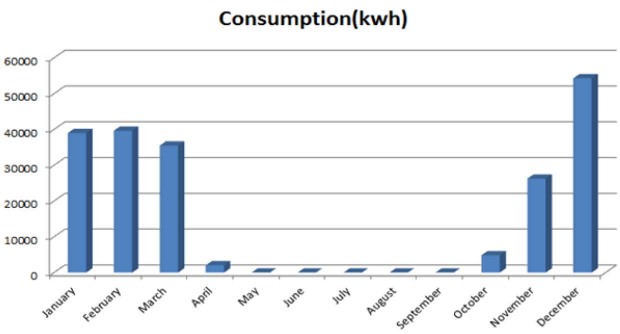


Fig. 3 Monthly consumption of natural gas for heating purposes

As already known, the electricity supply of the library building is made with two feeding lines from the substation of Technological Educational Institute (TEI) of Thessaly. The first line feeds, the panel of the external central cooling unit while the second line feeds the general building panel. The general building panel then feeds the subpanels of the building and hence all its loads.

The Efergy e2 classic electric meter has been installed in the building's general panel, where it helps to record the electricity consumption of the second power supply.

For the electrical consumption of the first power supply, which concerns the central cooling unit, there is no meter exclusively for this unit. Thus, an approach to the consumption of this electric current is then made.

The Efergy e2 classic wireless power meter offers detailed power consumption information. As mentioned above, it is installed in the general building table. Through the elink software, the data are stored and processed in digital form. The data capture taken into account in this work concerns a full calendar year (reporting period: 01/09/2016-31/08/2017).

Fig. 4 below shows a screenshot of the elink software, showing energy consumption for one month, its cost (in €), with a charge of 0.0643 €/kWh and carbon dioxide (in kg), where for electricity they amount to 0.998 kg CO_2/kwh.

TABLE I
ANNUAL AND MONTHLY CONSUMPTION OF NATURAL GAS FOR HEATING PURPOSES

Month	Consumption (kWh)	Total annual consumption (kWh)
January	38,988.73	
February	39,632.2	
March	35,472.83	
April	2,026.73	
May	0	
June	0	
July	0	20,1473.62
August	0	
September	0	
October	4,821.26	
November	26,245	
December	54,286.87	

Fig. 4 Monthly electrical consumption of 2nd power supply

The average monthly electricity consumption is 6,713.144 kWh, and the total annual electricity consumption is

80,557.724 kWh as shown on Table II.

TABLE II
ANNUAL AND MONTHLY CONSUMPTION OF ELECTRICAL LOADS OF 2ND POWER SUPPLY

	Month	Consumption (kWh)
2016	September	7,032.630
	October	6,311.879
	November	7,563.305
	December	6,990.455
2017	January	7,058.712
	February	7,275.923
	March	7,620.276
	April	6,049.567
	May	5,460.510
	June	6,447.759
	July	6,869.365
	August	5,877.343
	Annual total	80,557.724
	Average	6,713.144

An approximate calculation of the electricity consumption is then made, which concerns only the central cooling unit (1st power supply), since there are no data on its consumption. The data on which this approximate calculation are derived from a bibliographic survey [4] from which the average annual final energy consumption is 138 kWh/m^2.

So, the total annual consumption of the building is estimated to be:

$$138\frac{kWh}{m^2}\cdot 2{,}772.66\text{m}^2 = 383{,}627.08\,\text{kWh} \tag{1}$$

Considering the annual consumption of gas, electricity and total annual consumption, the annual cooling consumption is also calculated as follows:

$$382{,}627.08kWh - 201{,}473kWh - 80{,}557.724kWh = 100{,}595.736kWh \tag{2}$$

All the library building consumption data have been calculated and presented in Table III.

V. ENERGY SAVING MEASURES VIA RETSCREEN

The RETScreen Expert (version used in this paper) is a Microsoft Excel-based "clean" energy analysis software tool that consists of tabs/spreadsheets that communicate and interact with each other. The user enters his/her project data (such as location, project attributes and equipment) into the corresponding tabs, and the program then calculates the energy and financial sizes.

The software enables decision-makers to identify quickly and inexpensively the technical and economic viability of potential renewable energy projects, energy efficiency and cogeneration. Fig. 5 shows the operating environment and software tabs.

TABLE III
CUMULATIVE ANNUAL ENERGY CONSUMPTION TABLE BY FORM OF ENERGY

Form of energy	Natural gas	Electric energy	
Consumption description	Natural gas boiler/Heating	Central cooling unit/Cooling (1st power supply)	Electric loads (2nd power supply)
Annual consumption (kwh)	201,473.62	100,595.736	80,557.724
Total annual consumption (kwh)		382,627.08	

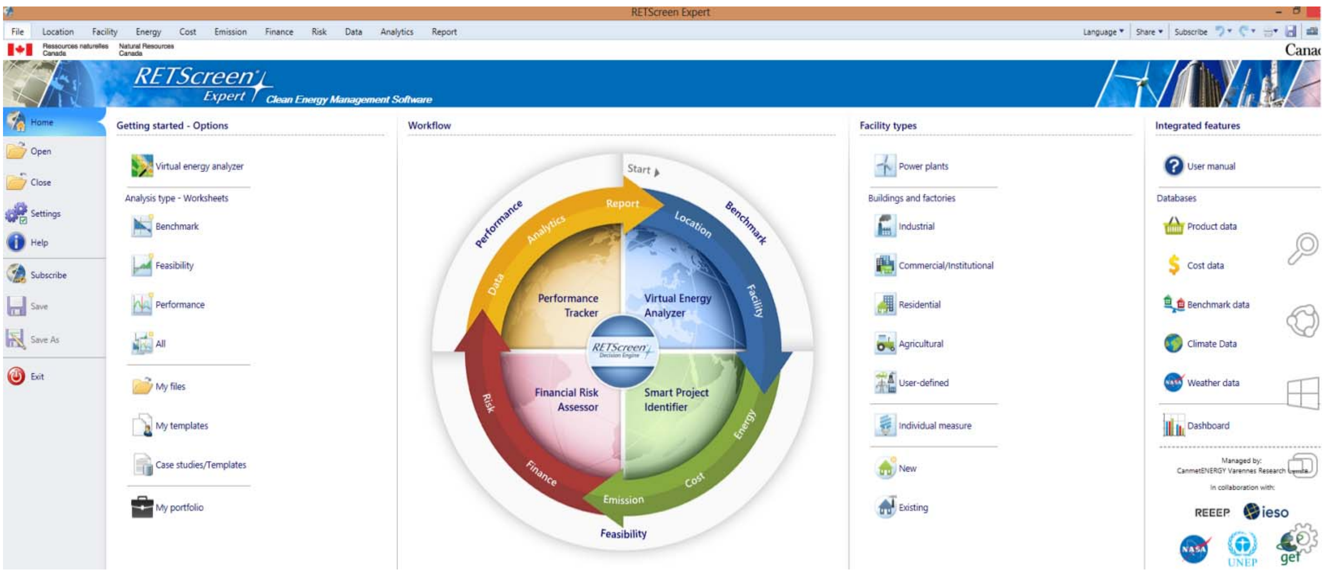
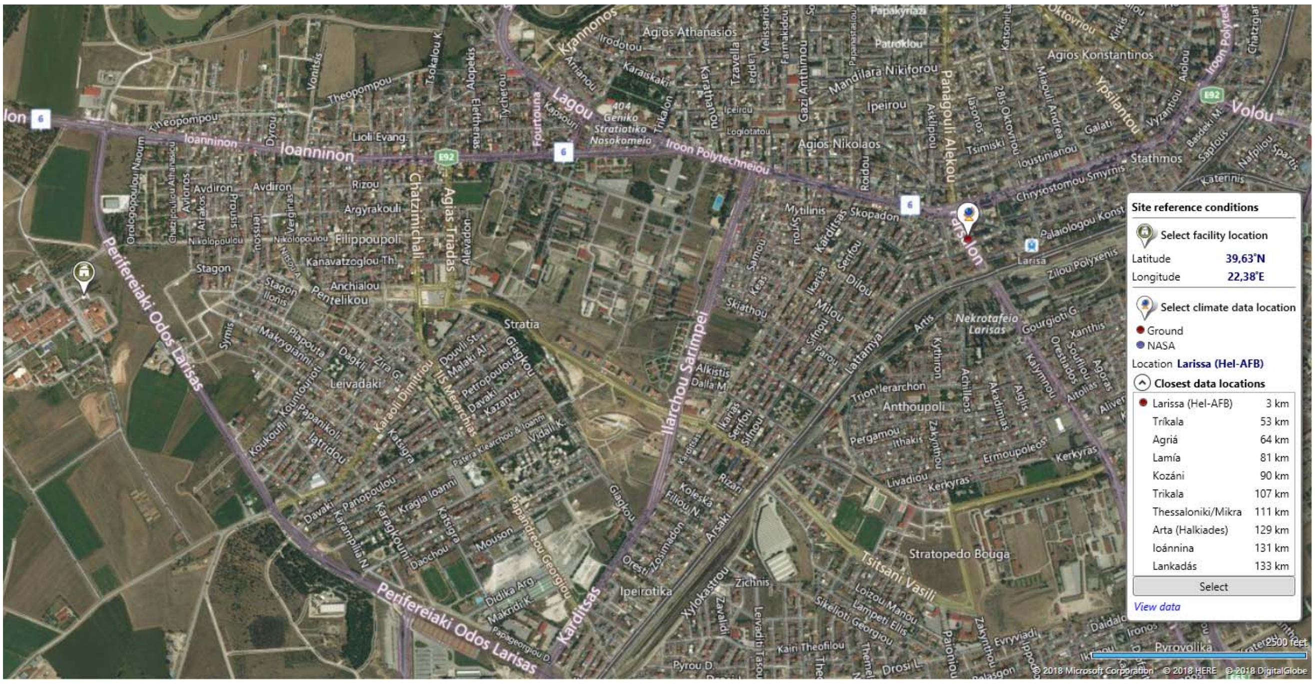


Fig. 5 RETScreen Expert Environment

Initially, the type of project from the Virtual Energy Analyzer and the particular type of installation are selected.

Then, the exact location of the installation and the climatological data station are selected from the map and the closest climatic data station available from the program, which is located in Larissa, as shown in Fig. 6 (a). Once the station has been selected, the program automatically loads the corresponding climatological data (Fig. 6 (b)).



(a)

	Unit	Climate data location	Facility location	Source
Latitude		39,6	39,6	
Longitude		22,4	22,4	
Climate zone		4A - Mixed - Humid		Ground+NASA
Elevation	m	74	0	Ground – Ground
Heating design temperature	°C	-3,2		Ground
Cooling design temperature	°C	34,4		Ground
Earth temperature amplitude	°C	22,6		NASA

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	4,8	81,3%	91,59	1,95	97,3	1,2	3,4	409	0
February	5,8	75,8%	71,00	2,67	97,2	1,5	5,0	342	0
March	8,9	73,1%	81,18	3,68	97,1	1,9	9,4	282	0
April	13,2	69,7%	61,70	4,83	96,8	1,8	15,4	144	96
May	18,6	64,3%	56,91	5,68	96,9	1,9	22,0	0	267
June	23,9	53,4%	55,57	6,91	96,9	2,3	27,6	0	417
July	26,0	52,2%	48,60	6,79	96,8	2,2	30,3	0	496
August	25,3	55,9%	37,44	6,09	96,9	2,0	29,6	0	474
September	21,2	62,0%	69,12	4,76	97,1	1,8	24,6	0	336
October	16,0	72,3%	91,52	2,99	97,4	1,4	17,5	62	186
November	9,9	81,3%	124,82	1,95	97,3	1,1	10,0	243	0
December	5,7	84,6%	139,40	1,56	97,3	1,2	4,6	381	0
Annual	**15,0**	**68,8%**	**928,85**	**4,16**	**97,1**	**1,7**	**16,7**	**1.863**	**2.272**
Source	Ground	Ground	NASA	NASA	NASA	Ground	NASA	Ground	Ground
Measured at					m	10	0		

(b)

Fig. 6 (a) Location and climatic data station selection, (b) Climatological data

Subsequently, specific building information, as well as the total area that it occupies, is completed in the program. As mentioned above, the total area of the building amounts to 2,772.66 m^2.

As aforementioned, the building consumes natural gas for heating and electricity for cooling and other electrical appliances. Taking into account the respective billing rates, these data are also entered in the program as shown in Fig. 7. The gas price used is equal to 0.6125 €/m^3, while the corresponding electricity charge is equal to 0.0597 €/kWh.In addition, the heating and cooling systems installed in the building are imported and all the building envelope elements (lighting, electrical equipment, etc.) are reported in detail. The building consists of three levels, as described previously. Thus, these levels are imported into the program, with a detailed description of the properties of the building shell (walls, openings, floors, ceilings, coefficients of thermal conductivity, volume, etc.). Also, the orientation of the building is imported.

Once the building has been set up, at this point the possibility of displaying the fuel and electricity consumption without having implemented any energy saving measure is given, as shown in Fig. 8.

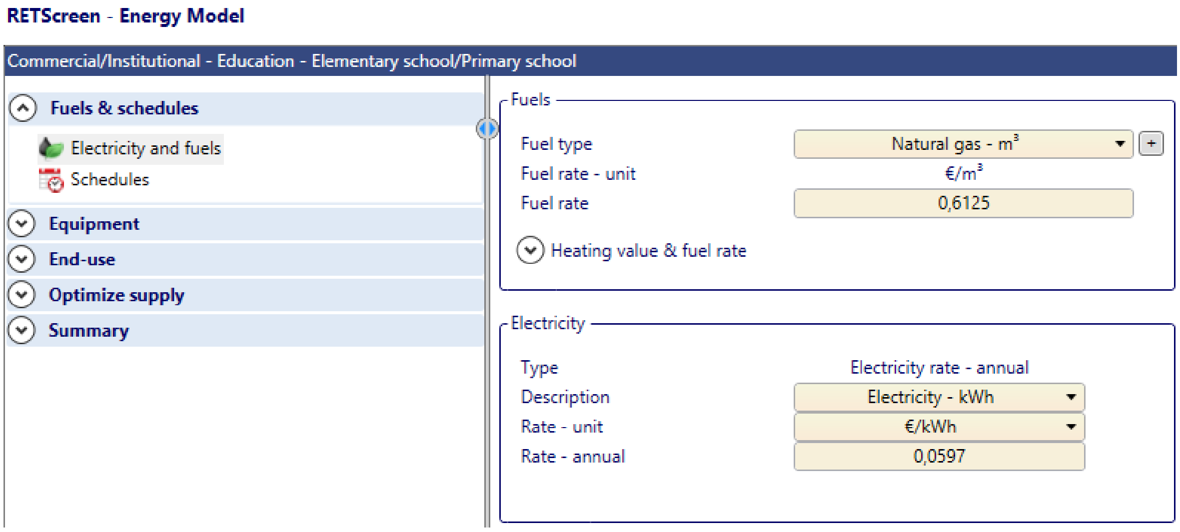
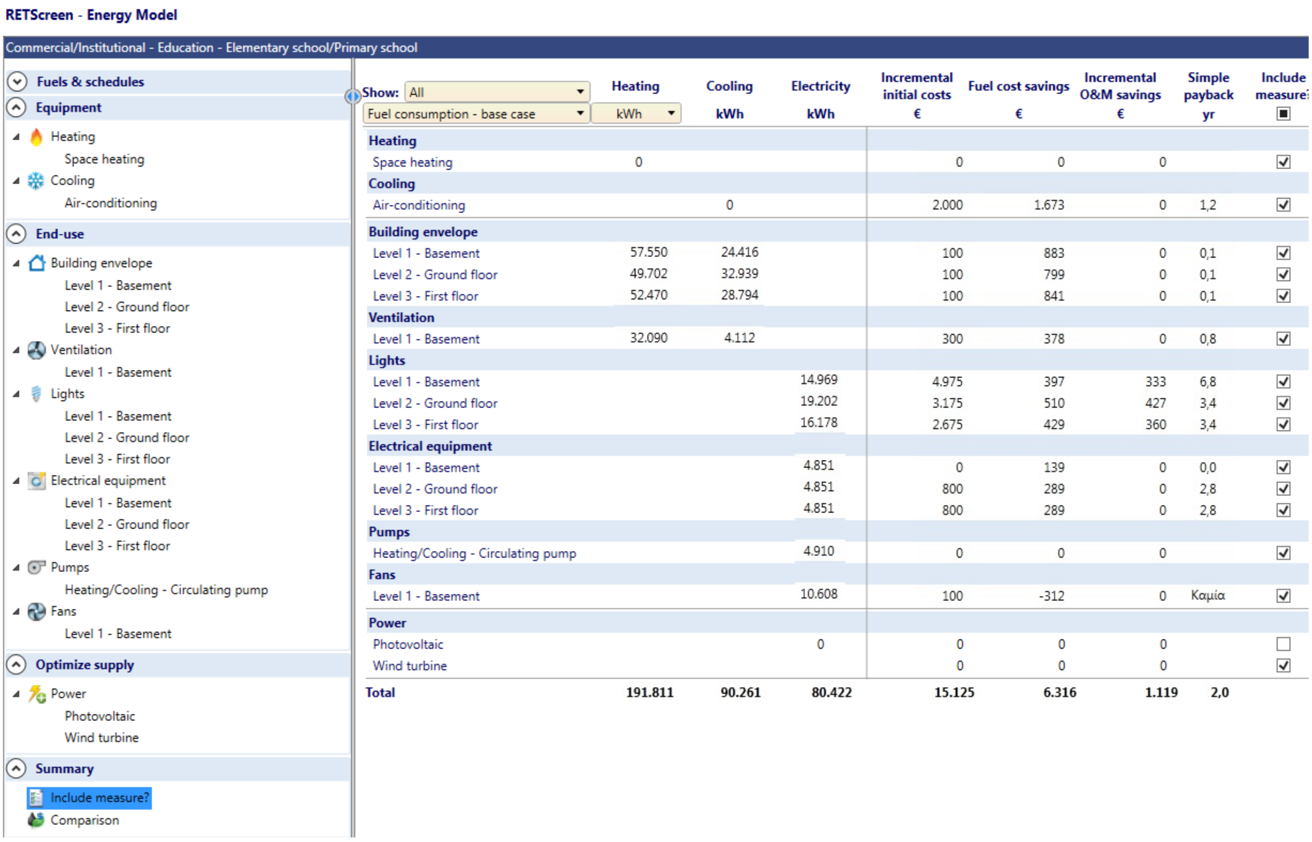


Fig. 7 Electric energy and fuels



	Heating kWh	Cooling kWh	Electricity kWh	Incremental initial costs €	Fuel cost savings €	Incremental O&M savings €	Simple payback yr	Include measure?
Heating								
Space heating	0			0	0	0		✓
Cooling								
Air-conditioning		0		2.000	1.673	0	1,2	✓
Building envelope								
Level 1 - Basement	57.550	24.416		100	883	0	0,1	✓
Level 2 - Ground floor	49.702	32.939		100	799	0	0,1	✓
Level 3 - First floor	52.470	28.794		100	841	0	0,1	✓
Ventilation								
Level 1 - Basement	32.090	4.112		300	378	0	0,8	✓
Lights								
Level 1 - Basement			14.969	4.975	397	333	6,8	✓
Level 2 - Ground floor			19.202	3.175	510	427	3,4	✓
Level 3 - First floor			16.178	2.675	429	360	3,4	✓
Electrical equipment								
Level 1 - Basement			4.851	0	139	0	0,0	✓
Level 2 - Ground floor			4.851	800	289	0	2,8	✓
Level 3 - First floor			4.851	800	289	0	2,8	✓
Pumps								
Heating/Cooling - Circulating pump			4.910	0	0	0		✓
Fans								
Level 1 - Basement			10.608	100	-312	0	Καμία	✓
Power								
Photovoltaic			0	0	0	0		☐
Wind turbine				0	0	0		✓
Total	**191.811**	**90.261**	**80.422**	**15.125**	**6.316**	**1.119**	**2,0**	

Fig. 8 Fuel/electricity consumption-base case

Once the library building has been created with its features, with the help of the RETScreen software, the energy saving potential of the particular building can now be realized after the energy saving measures have been implemented. Each measure is being examined separately in the next chapters.

A. Lamps Replacement

Replacing bulbs with led technology leads to energy savings of 44.4% for each level and a total annual energy savings of 22.377 kwh. Their total cost of replacement is € 13.325 (average cost of €25 per lamp). It seems, therefore, that replacing the lamps is an advantageous energy, both in terms of energy saving and economic.

B. Floor/Wall/Ceiling Insulation

It is noted that with the thermal insulation of walls a total annual energy of 3,054 kWh is saved for heating and 1,911 kWh for cooling. In conclusion, it hardly contributes to energy savings. This is because the thermal insulation coefficients of the walls are already quite small and approaching 0.45 W / m^2 ºC, which is also the maximum allowable coefficient for the climate zone C in Greece. Moreover, the initial cost increase reaches €37,380, with an average insulation price of 25 €/m^2. So, the application of thermal insulation for the results that it offers is unprofitable.

For the same reasons, the application of thermal insulation to the roof and / or floor of the building is not advisable.

Illumination level – calculator		Base case	Proposed case
Lamp & fixture type		Fluorescent T5 - high output EB	Light emitting diode (LED)
Efficiency	lm/W	85,5	100
Electricity load per lamp	W	18	10
Number of lamps per fixture		4	4
Miscellaneous losses	W		
Electricity load per fixture	W	72	40
Number of fixtures		333	333
Number of lamps - total .		1.332	1332
Operating hours	h/yr	2.100	2.100
Costing method			
Number of lamps - initial costs	lamp	0	99
Initial costs - lamp	$/lamp	18	25
Incremental initial costs - other	$		2.500
Incremental initial costs - total	$		4.975
Lamp life	h	20.000	50.000
Lamp replacement frequency	yr	9,5	23,8
Incremental O&M savings			1.119
Number of units		1	1
Electricity	kWh	50.349	27.972
Energy saved		22.377 kWh	44,4%

Fig. 9 Saving energy from lamp replacement

				Energy saved
Number of building envelope units		1	1	
System selection		Heating & cooling	Heating & cooling	
Heating system		Space heating	Space heating	
Heating	kWh	129.411	126.357	3054
Cooling system		Cooler	Cooler	
Cooling	kWh	232.360	230449	1911

Fig. 10 Saving energy from insulating walls

C. Openings Replacement

Replacement of openings (windows) is performed with openings with a thermal transmittance of 2.8 W /m^2°C, as long as the maximum allowable coefficient for openings in climatic zone C. The total annual energy savings achieved is 13,854 kWh for the heating and 8,848 kWh for cooling.

Taking an average of 80 €/m^2, the total cost is €43,698. Replacing the openings (windows) contributes to a good degree in terms of energy savings in heating and cooling, but it is an expensive investment.

The doors of this building are not considered for the potential for energy savings, as they occupy a very small percentage of the total area, and therefore the resulting energy savings are negligible.

D. Placement of External Shading

External shading saves 14,009 kWh per year in cooling. Its cost (with an average placement price of 25€/m^2) is at €13,656 and is therefore considered a good solution for the energy savings of the cooling system. However, the building should not be shaded in winter as this will have adverse effects on the energy consumption for heating in the winter.

Number of building envelope units		1	1	
System selection		Heating & cooling	Heating & cooling	**Energy saved**
Heating system		Space heating	Space heating	
Heating	kWh	129.411	115.557	13.854
Cooling system		Cooler	Cooler	
Cooling	kWh	232.360	223.511	8.848

Fig. 11 Saving energy from openings replacement

Incremental initial costs - total	€		13.656	
Incremental O&M savings	€			
Number of building envelope units		1	1	
System selection		Heating & cooling	Heating & cooling	**Energy saved**
Heating system		Space heating	Space heating	
Heating	kWh	129.411	129.411	0
				0%
Cooling system		Air-conditioning	Air-conditioning	
Cooling	kWh	232.360	218.351	14.009
				6%

Fig. 12 Saving energy from placing external shading

Illumination level – calculator		**Base case**	**Proposed case**	**Energy saved**
Lamp & fixture type		Fluorescent T8 - electronic ballast	Light emitting diode (LED)	
Efficiency	lm/W	85,5	100	
Electricity load per lamp	W	18	10	
Number of lamps per fixture		4	4	
Miscellaneous losses	W			
Electricity load per fixture	W	72	40	
Number of fixtures		99	99	
Number of lamps - total		396	396	
Operating hours	h/yr	2.100	1.800	
Costing method		Επίπεδο 2		
Number of lamps - initial costs	lamp	0	99	
Initial costs - lamp	€/lamp	18	25	
Incremental initial costs - other	€		2.500	
Incremental initial costs - total	€		4.975	
Lamp life	h	20.000	50.000	
Lamp replacement frequency	yr	9,5	27,8	
Incremental O&M savings			392	
Number of units		1	1	
Electricity	kWh	14.969	7.128	7.841
				52,4%

Fig. 13 Saving energy from placing BMS

E. Placement of BMS

Importing a BMS system into the RETScreen software is not a feature of the program. However, considering that a BMS system can manage all electromechanical installations to provide thermal and visual comfort conditions for users, the only way to look at energy savings from such a system is to assume that the total hours of operation of the devices will be reduced to a minimum, without spending energy that is not being used.

As an example, is referred the reduction of the operating time of the luminaires by mounting motion detectors, for example. Thus, at Level 1 (Basement), if there are any motion detectors placed in addition with the replacement of the lamps, the total operating hours will be reduced, and overall energy savings are shown in Fig. 13.

Total energy savings in this case are projected to 52.4%. Respectively, energy can be saved on other levels and not just on lighting.

VI. Renewable Energy Sources on the Building Using RETScreen

As aforementioned, two scenarios are examined using the RETScreen software. In the first case, the installation of a PV array and/or a wind turbine with a power of 50 kW is examined and in the second case the installation of a PV array and/or a wind turbine of 100 kW is investigated.

A. Installing a Photovoltaic Array of 50kW

With the installation of a PV array [6] of 50 kW, an annual energy saving of 63,047 kWh is accomplished, as shown in the above figure. Of course, this energy is saved when the photovoltaic array is positioned facing the South (optimal positioning) [5]. The required surface for the installation of PV panels amounts to 337 m^2 and can be easily placed on the roof of the building, since the total roof area is 860.42 m^2.

The initial cost of installing PV panels is € 75,388 (1,500 €/KW), while the maintenance cost is € 2,109 (42 €/KW/year). Fig. 15 shows the economic analysis provided by the software. For receipts from the sale of electricity to the grid produced through PV, a sales price of 0.12€/kwh is obtained. Also, the project is being considered for a 20-year contract, without funding from a program.

Taking into account the results of the software economic analysis, it seems that such an investment is not economically advantageous. The net present value of the project is negative, the repayment of the shares takes place at the end of the 13th year and the total cost is not depreciated during the 20-year contract.

B. Installing a Photovoltaic Array of 100kW

With the installation of a PV array of 100 kW, an annual energy saving of 125,478 kwh is achieved, as shown in the above figure. The initial cost of PV panels is 149,940€ (1,500 €/KW) and the maintenance cost is 4,198 € (42 €/KW/year). Fig. 17 shows the economic analysis, while the same assumptions are taken into account with those in the analysis of the PV array of power of 50 kW.

Considering the results of the software economic analysis, it appears that while the initial cost of installation is greater than the equivalent of the PV power unit of 50 kW, the investment is cost-effective. The net present value of the project is positive, the repayment of the shares takes place at the end of the 10th year, while the benefit-cost ratio is higher than the unit.

The environmental benefits of installing the PV array and implementing the energy saving measures are outlined in Fig. 18 where it appears that the total annual greenhouse gas emission reduction is 134.9 tons, equivalent to 57,961.3 litres of unleaded petrol.

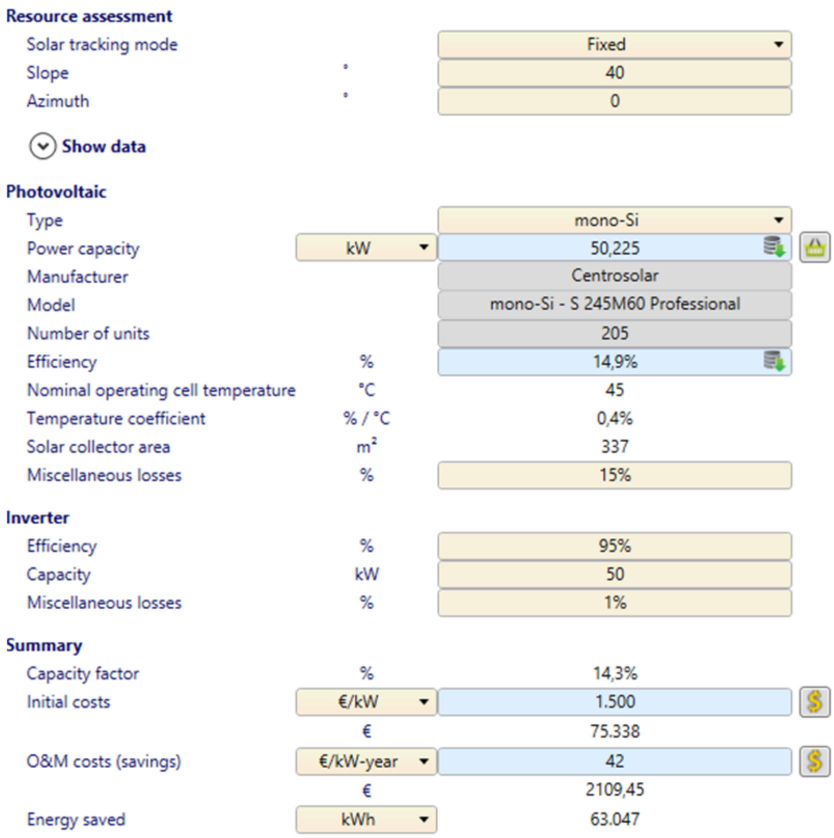


Fig. 14 Photovoltaic array of 50 kW

Financial parameters

General		
Fuel cost escalation rate	%	2%
Inflation rate	%	2%
Discount rate	%	9%
Project life	yr	20
Finance		
Incentives and grants	€	
Debt ratio	%	70%
Debt	€	107.392
Equity	€	46.025
Debt interest rate	%	7%
Debt term	yr	15
Debt payments	€/yr	11.791
Income tax analysis	☐	

Annual revenue

GHG reduction revenue		
Gross GHG reduction	tCO_2/yr	87
Gross GHG reduction - 20 yrs	tCO_2	1.731
GHG reduction revenue	€	0
Other revenue (cost)	☐	
Clean Energy (CE) production revenue	☑	
CE production	MWh	63
CE production credit rate	€/kWh	0,12
	€	7.566

Fuel type	Electricity exported to grid MWh	Clean energy
Solar	63	Yes

Costs | Savings | Revenue

Initial costs			
Incremental initial costs	100%	€	153.416
Total initial costs	**100%**	**€**	**153.416**
Annual costs and debt payments			
O&M costs (savings)		€	791
Fuel cost - proposed case		€	14.191
Debt payments - 15 yrs		€	11.791
Total annual costs		**€**	**26.773**
Annual savings and revenue			21.476
Fuel cost - base case		€	7.566
Total annual savings and revenue		**€**	**29.041**

Financial viability

Pre-tax IRR - equity	%	8,5%
Pre-tax IRR - assets	%	-0,85%
Simple payback	yr	10,9
Equity payback	yr	13,9
Net Present Value (NPV)	€	-2.475
Annual life cycle savings	€/yr	-271
Benefit-Cost (B-C) ratio		0,95
Debt service coverage		1,2

Yearly cash flows

Year #	Pre-tax €	Cumulative €
0	-46.025	-46.025
1	2.398	-43.627
2	2.530	-41.097
3	2.665	-38.432
4	2.803	-35.628
5	2.944	-32.685
6	3.087	-29.597
7	3.233	-26.364
8	3.383	-22.982
9	3.535	-19.447
10	3.690	-15.757
11	3.848	-11.909
12	4.010	-7.899
13	4.174	-3.724
14	4.342	618
15	4.514	5.132
16	16.480	21.611
17	16.658	38.269
18	16.840	55.109
19	17.025	72.134
20	17.214	89.348

Fig. 15 Economic analysis with appliance of energy saving measures and installation of photovoltaic array of 50 kW power

Resource assessment		
Solar tracking mode		Fixed
Slope	°	40
Azimuth	°	0
Show data		
Photovoltaic		
Type		mono-Si
Power capacity	kW	99,96
Manufacturer		Centrosolar
Model		mono-Si - S 245M60 Professional
Number of units		408
Efficiency	%	14,9%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0,4%
Solar collector area	m^2	671
Miscellaneous losses	%	15%
Inverter		
Efficiency	%	95%
Capacity	kW	100
Miscellaneous losses	%	1
Summary		
Capacity factor	%	14,3%
Initial costs	€/kW	1.500
	€	149.940
O&M costs (savings)	€/kW-year	42
	€	4.198
Energy saved	kWh	125.478

Fig. 16 Photovoltaic array of 100 kW

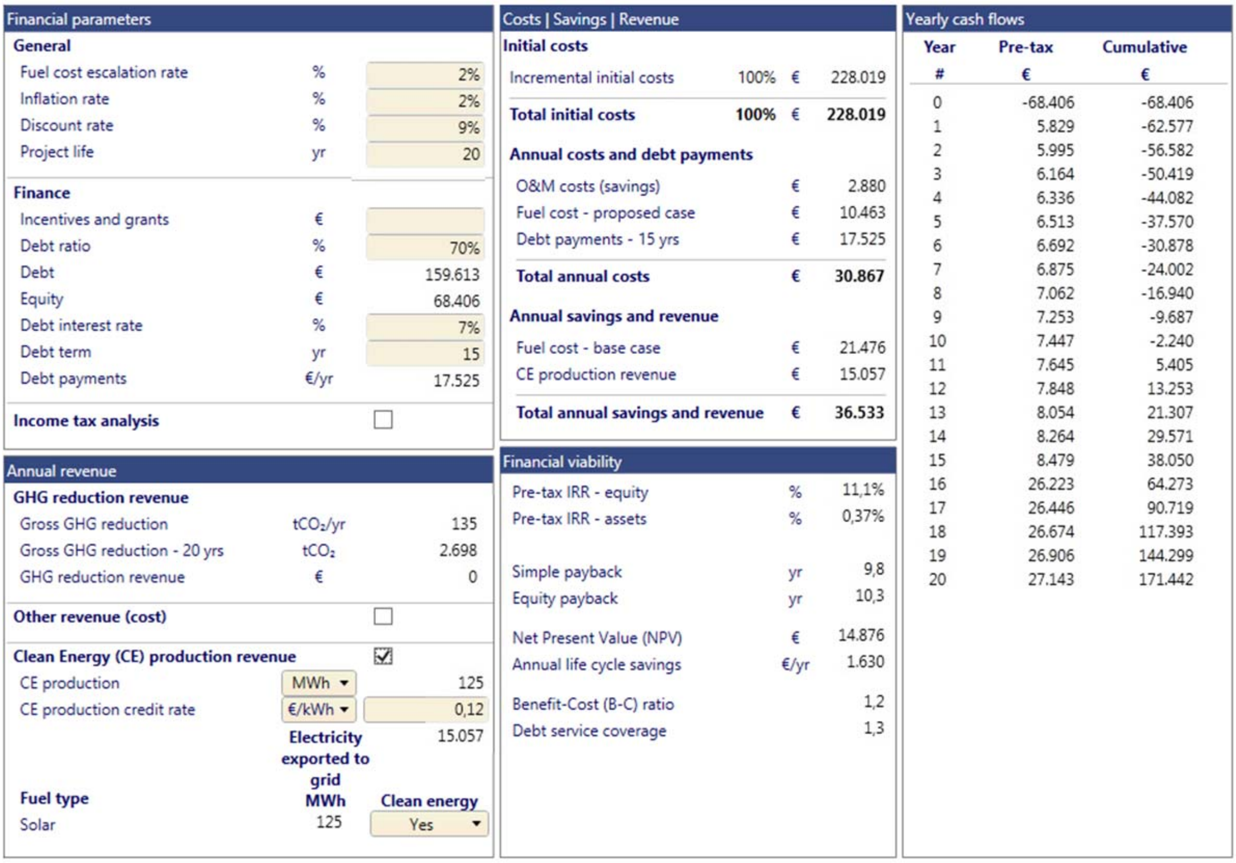


Fig. 17 Economic analysis with appliance of energy saving measures and installation of photovoltaic array of 100 kW power

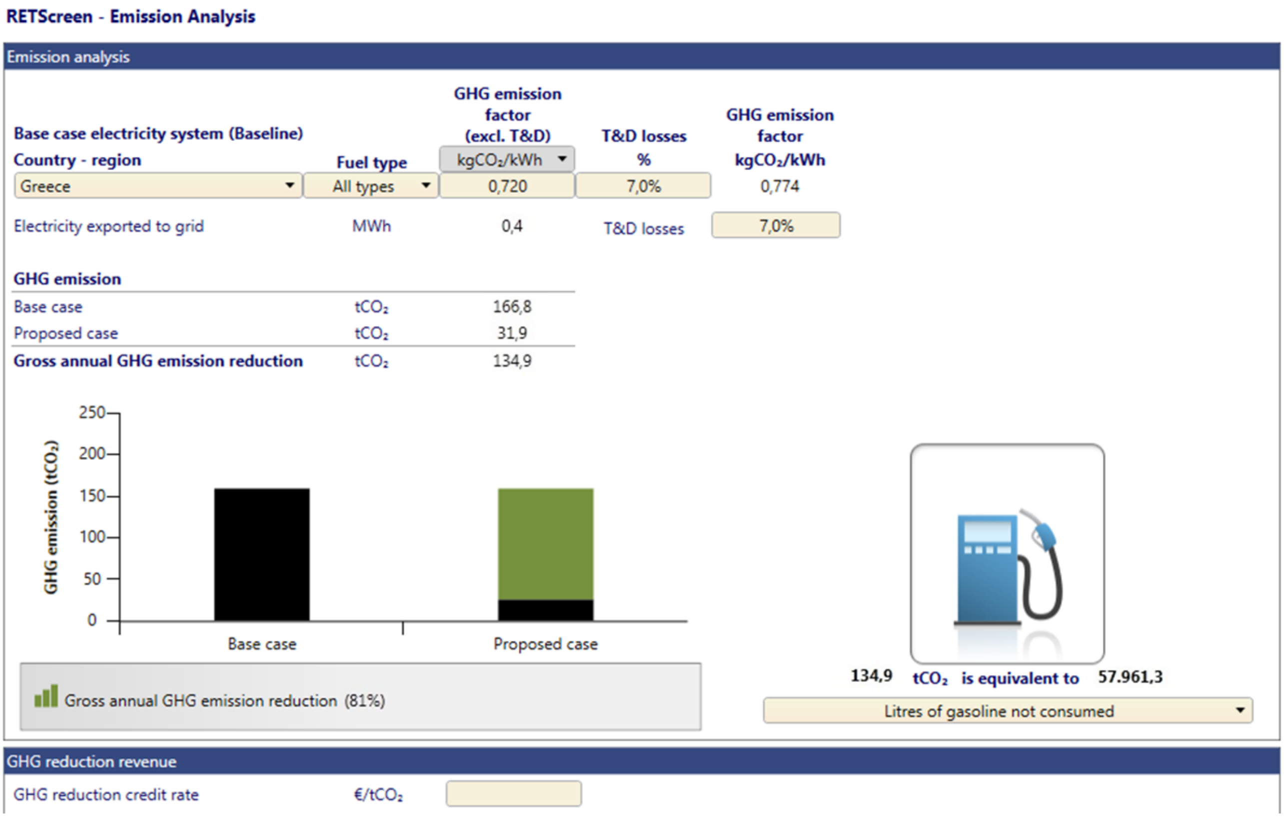


Fig. 18 Emission analysis with appliance of energy saving measures and installation of photovoltaic array of 100 kW power

C. Installing a Wind Turbine of 50kW

With the choice of the particular wind turbine, the software displays a warning, indicating that the wind potential is very low and therefore the wind turbine will not perform.

Examination of a different wind turbine is not advisable as the wind speed is too low (1.7 m/s, measured at 10 m). Moreover, around the building, there are many obstacles that prevent the wind.

D. Electric Energy Coverage

From the following pictures it is easy to see that the installation of a 100 kW PV array, covers fully the electrical consumption of the building (without the electricity consumed by the cooling unit, Fig. 20), while compared with the total electric power consumption (including the cooling unit) appears to cover quite a large percentage of it (Fig. 21).

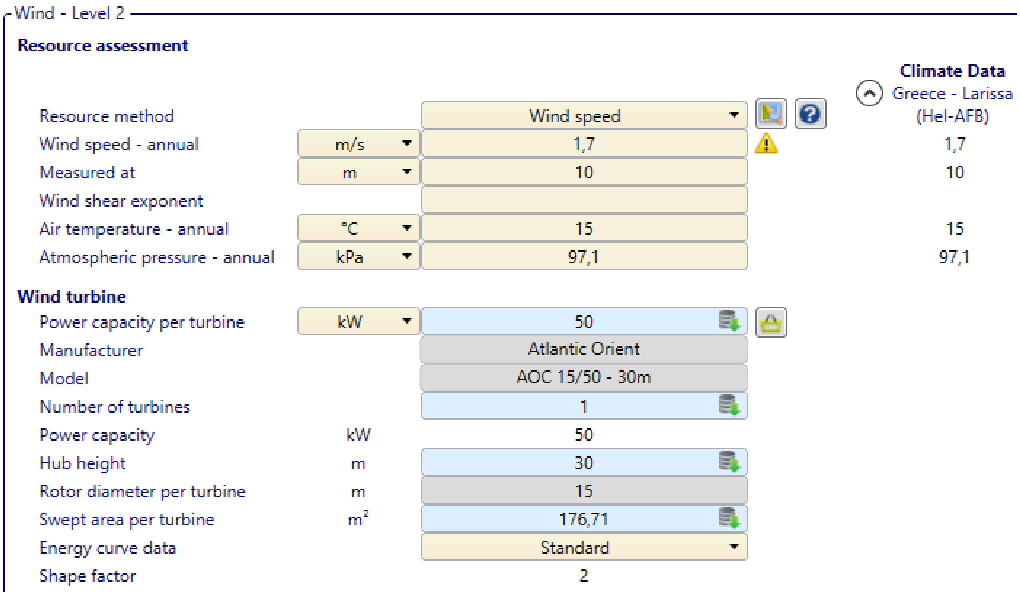


Fig. 19 Wind turbine of 50 kW

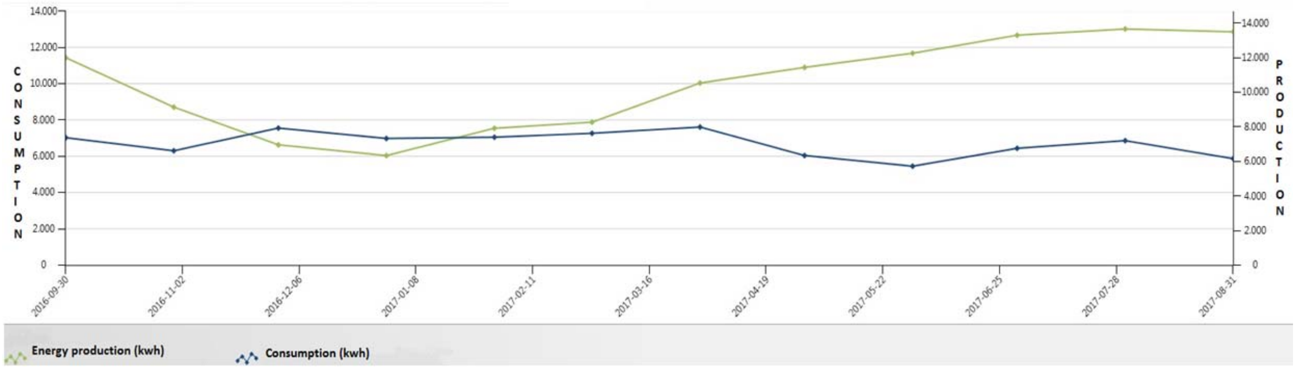


Fig. 20 Comparison of electricity consumption (without cooling) – PV array generation of 100 kW power

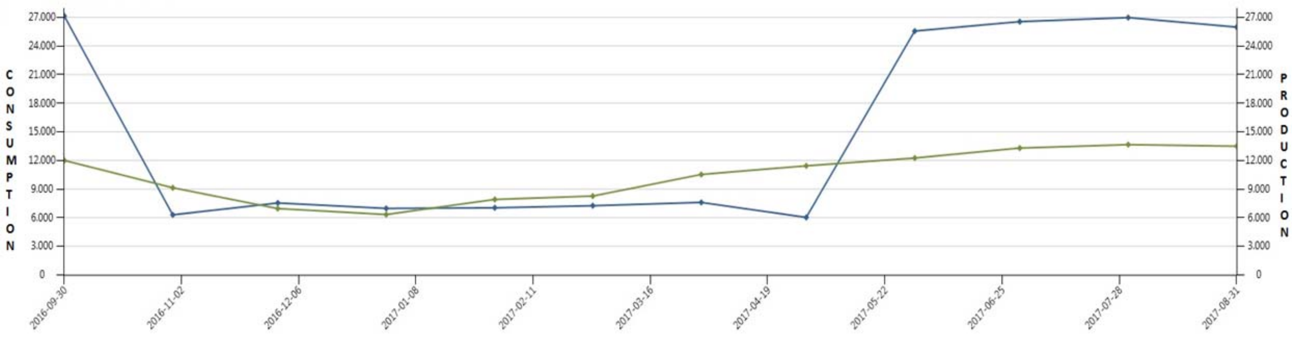


Fig. 21 Comparison of total electricity consumption – PV array generation of 100 kW power

VII. Renewable Energy Sources on the Building Using HOMER

Initially, data are loaded into the program to process and ultimately propose the optimal solution. The data are the same as those used in the RETScreen, 50 kW and 100 kW power PV arrays, 50 kW and 100 kW power wind turbines, and of course the electrical consumption load. The grid is considered interconnected in the main grid rather than stand-alone. One major difference that deserves particular attention is the fact that the load should be described on an hourly basis rather than monthly as in RETScreen. So, with the help of recording the electricity consumption of the Efergy e2 meter, 8,760 values are entered in the software, which have been initially entered in a text file (.txt) so they can be read by it.

The input of load values is shown in Fig. 22. Subsequently, the cost of the electricity of the grid and the sale of the generated electricity from RES are introduced. Subsequently, the cost of the electricity of the grid and the sale of the generated electricity from RES are introduced. Then, the PV arrays are inserted, giving the option in the program to choose between a PV power of 50 or 100 or none.

The wind turbines are inserted as shown in the following figures. An 80 kW wind turbine is available instead of 50 kW.

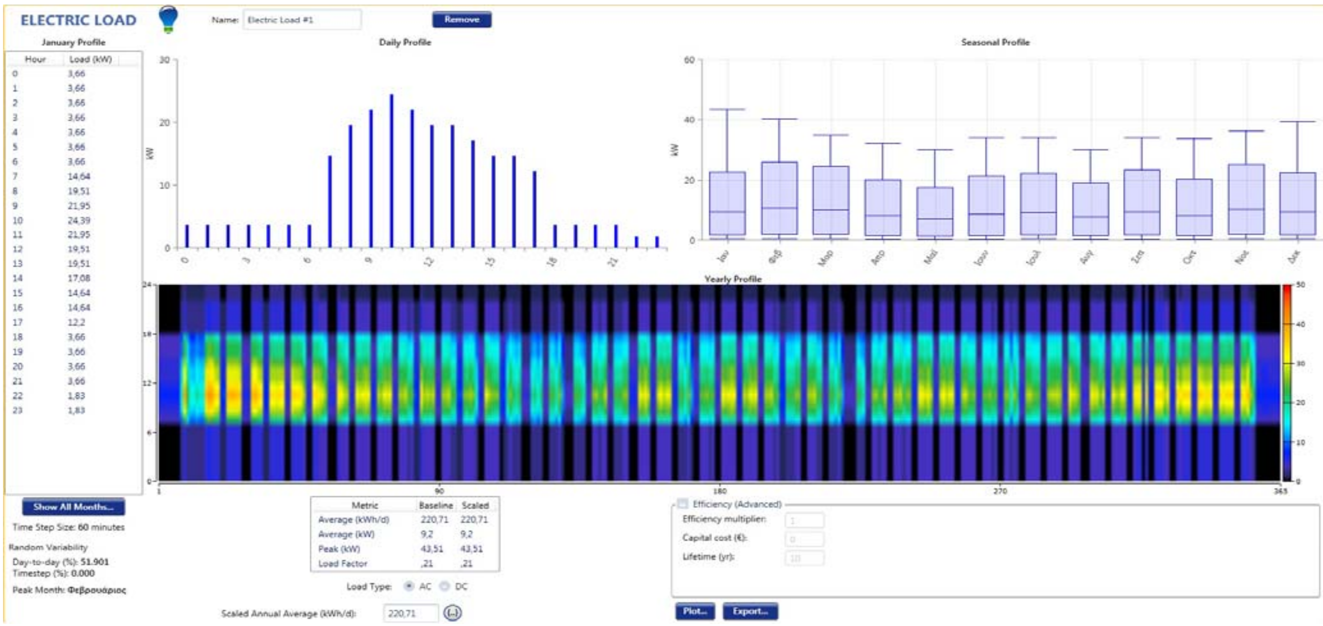


Fig. 22 Hourly load input

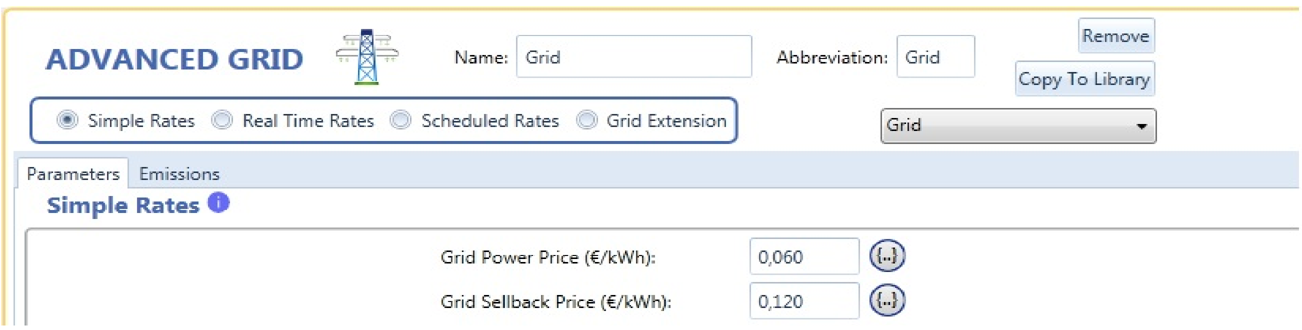


Fig. 23 Grid values input

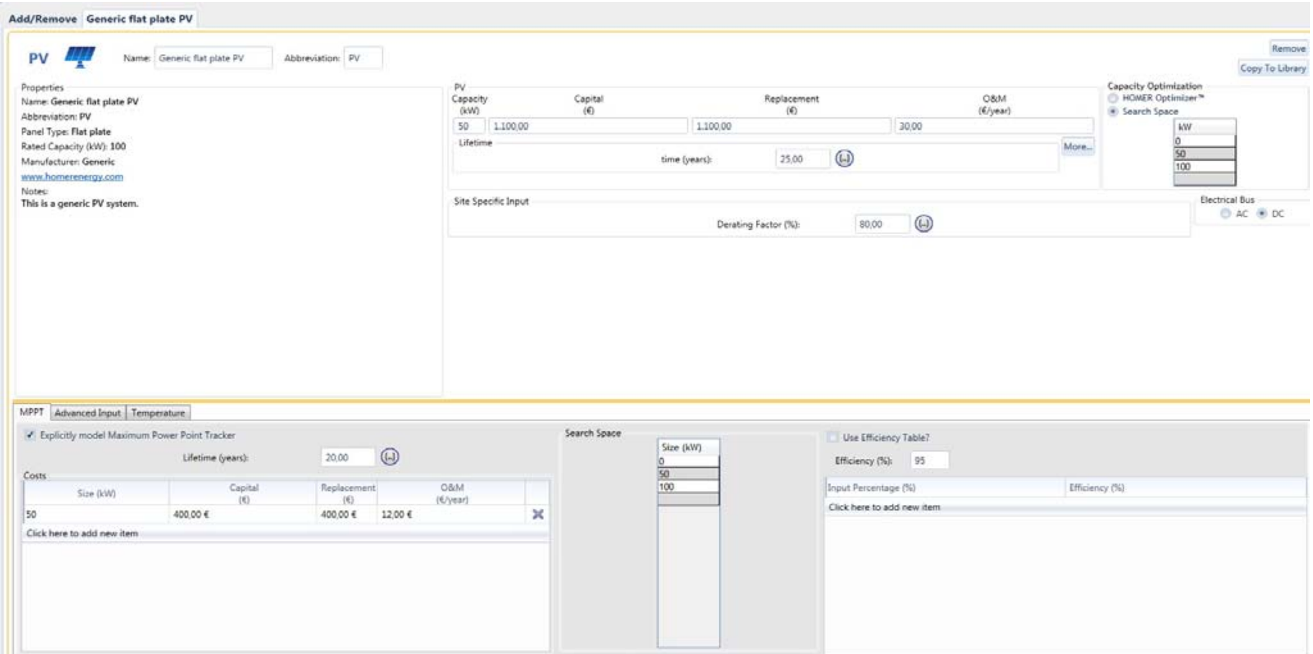
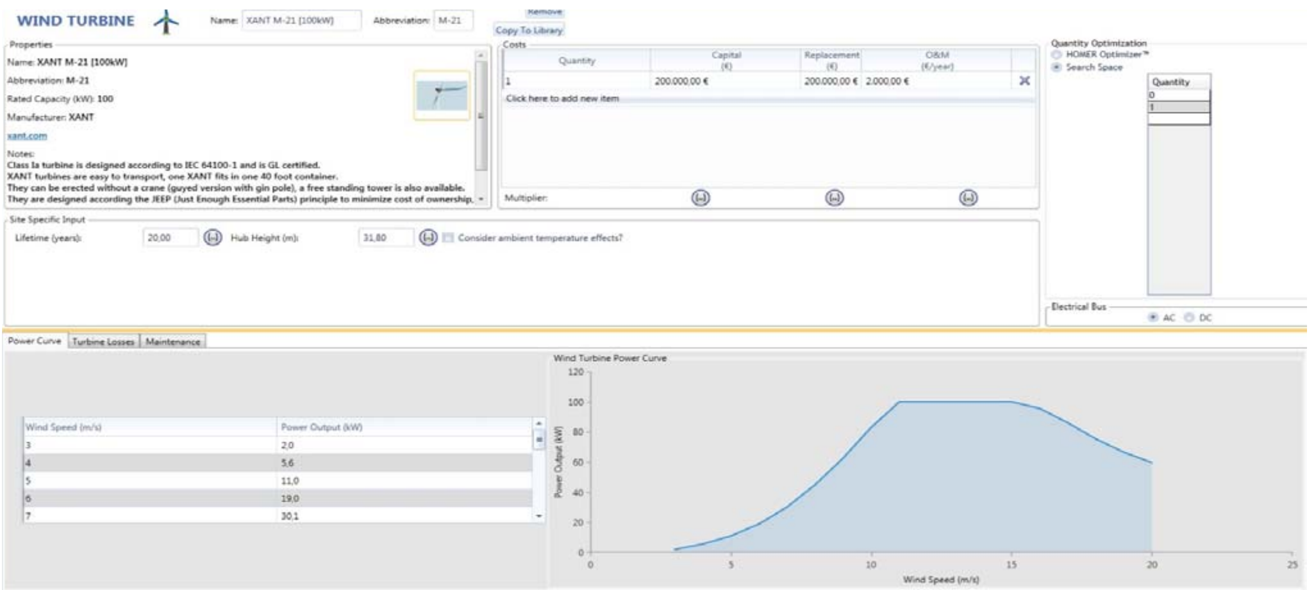
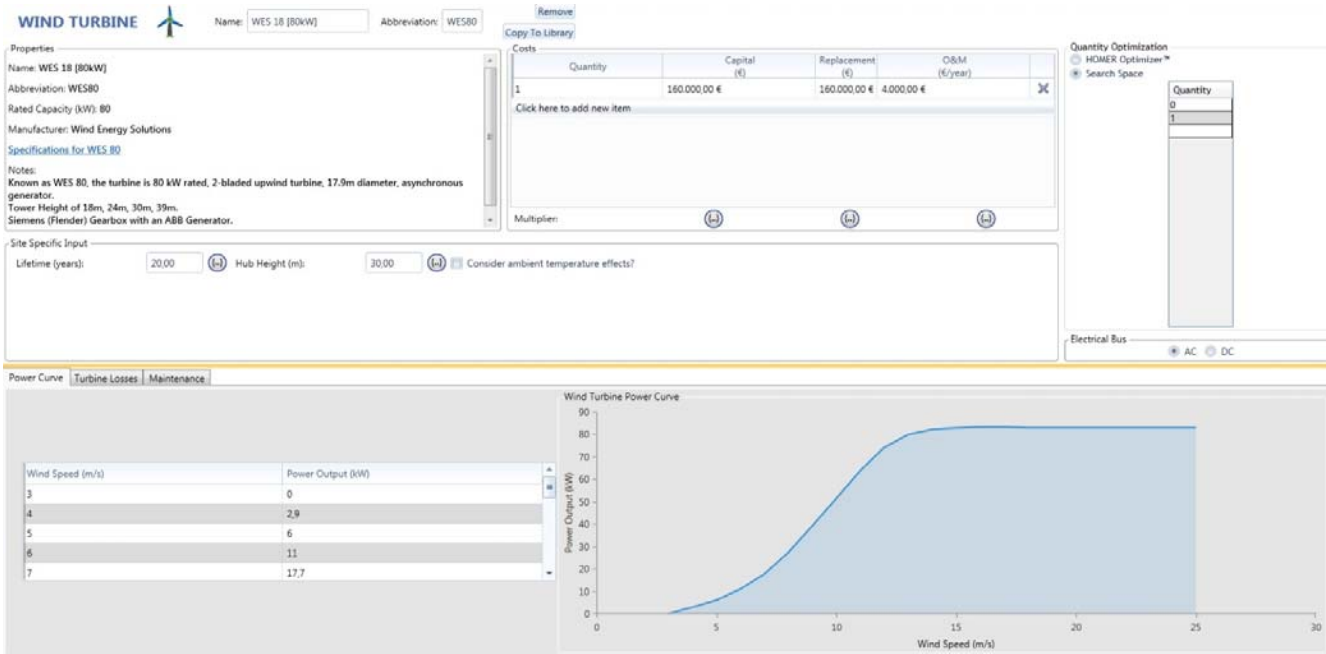


Fig. 24 PV array input



(a)



(b)

Fig. 25 Wind turbines input

Finally, the network being studied after entering the data has the following format. After entering the data, the program gives the best combinations, which are shown below.

From Fig. 27, it is concluded that the HOMER software selects as the first optimal solution the installation of 100 kW power PV array. The second-best option is to place neither a PV array, nor a wind turbine. It is also noted that the PV array of 50 kW power is not at all chosen as a solution.

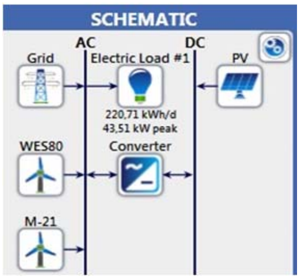


Fig. 26 Grid

Architecture							Cost			
PV (kW)	PV-MPPT (kW)	WES80	M-21	Grid (kW)	Converter (kW)	Dispatch	COE (€)	NPC (€)	Operating cost (€)	Initial capital (€)
100	100			999.999	100	CC	-0,0414 €	-71.729 €	-6.522 €	3.800 €
				999.999		CC	0,0600 €	55.973 €	4.833 €	0,00 €
100	100		1	999.999	100	CC	0,0228 €	59.443 €	-12.466 €	203.800 €
100	100	1		999.999	100	CC	0,0330 €	72.101 €	-7.919 €	163.800 €
100	100	1	1	999.999	100	CC	0,0617 €	196.092 €	-14.482 €	363.800 €
			1	999.999		CC	0,133 €	203.737 €	322,70 €	200.000 €
		1		999.999		CC	0,177 €	211.329 €	4.432 €	160.000 €
		1	1	999.999		CC	0,168 €	343.699 €	-1.408 €	360.000 €

Fig. 27 Optimum results

REFERENCES

[1] Climatic change-international negotiations-kioto protocol, Ministry of Environment and Energy, www.ypeka.gr.
[2] A. G. Rokkou, "Energy Saving-Lesson Notes in the Postgraduate Curriculum entitled" Energy Technologies and Automation Systems ", 2016, unpublished.
[3] G. Ageridis, Ath. Gaglia, G. Giannakidis, El. Daskalaki, Ar. Dimoudi, Ev. Dialynas, C. Doukas, M. Kteniadakis, K. Mpalaras, "Training of Energy Inspectors Educational Material A. Building Inspection Thematic Unit: DE1 Introduction to the Energy Sector", 2011, unpublished.
[4] D. Lalas, K. Balaras, A. Gaglia, S. Mirasgedis, E. Georgopoulou, I. Sarafidis, "Building stock, Energy conservation potential and emission reduction in the domestic and tertiary sector in Greece – Potential measures", Final Technical Report, Institute for Environment and Sustainable Development (IEPBA) - Ministry of Environment, Physical Planning and Public Works, 2002.
[5] I. E. Fragiadakis, "Photovoltaic Systems", Ziti publications, 2009.
[6] V. Dafopoulos, "Alternative Energy Forms II - Lesson Notes in the Postgraduate Curriculum entitled" Energy Technologies and Automation Systems ", 2016, unpublished.
[7] Energy-Renewable Energy Sources-Wind Energy, Ministry of Environment and Energy, www.ypeka.gr.
[8] J. F. Walker, N. Jenkins, "Wind Energy and Wind Turbines", Ion Publications, 2007.
[9] Panhellenic Association of Anonymous Technical Companies & Ltd., "For Energy Saving in Buildings", 2008, unpublished.

[10] CANMET Energy Technology Centre – Varennes (CETC), “Clean Energy Project Analysis RETScreen Engineering & Cases Textbook”, Third Edition, Ministry of Natural Resources Canada, 2001-2005.
[11] HOMER Pro Microgrid Analysis Tool x64, 3.10.1. (Evaluation Edition), Help Contents, www.homerenergy.com.
[12] G. Alevizos, "Energy Saving in Buildings", NTUA, Faculty of Electrical and Computer Engineering, 2013, unpublished.
[13] S. Tsesmelis, "Energy demand: Building framework-area of visa", 96 pages, University of the Aegean, MSc. Environmental Policy and Management of the Department of the Environment, 2006, unpublished.