TECHNOLOGICAL EDUCATIONAL INSTITUTE OF WESTERN GREECE
DEPARTMENT OF MECHANICAL ENGINEERING T.E.
POSTGRADUATE STUDIES PROGRAM:
«RENEWABLE ENERGY SYSTEMS»

THESIS

ENGINEERING AND ECONOMICAL STUDY FOR INSTALLATION AND OPERATION OF A P/V SYSTEM IN A SMALL HOTEL LOCATED IN ZAKYNTHOS

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FOREWORD

The present issue constitutes the Diploma Thesis which prepared in Graduate Program of the Department of Mechanical Engineering T.E. of Technological Educational Institute of Western Greece, with title: «*Renewable Energy Systems*» and refers to the methodology of sizing of P/V Systems and the benefits arising from the establishment of such a system which belong to the category of mild forms of energy. It is known that many residences, modern industries and owners of parcels increasingly use the P/V Systems, because they provide economic energy environmentally friendly.

Initially, it is studied the adjustment of an existing small hotel complex located in Zakynthos, to the local climatic conditions of Zakynthos with the help of Olgyay's & Givoni's Bioclimatic Charts. Then followed calculation of the mean Coefficient of Thermal Transmittance of the building and it becomes a proposal for its energy upgrade. Subsequently, it becomes study for sizing of the P/V System to cover the electrical loads of the hotel complex, the calculation of the energy produced by this P/V System and the calculation of excess or lack of energy by this P/V System according to the electrical loads, the available solar potential and the ageing of the photovoltaics. Finally, it becomes an techno-economic study to see if the installation of the PV System is an advantageous investment considering many factors.

I warmly thank my supervisor Mr. Panagiotis Kakavas, Assistant Professor of the Department of Civil Engineering T.E., for valuable assistance and guidance he offered me for the embodiment of this work.

Dimitrios Chountalos
November 2015

Υπεύθυνη Δήλωση Φοιτητή: Ο κάτωθι υπογεγραμμένος φοιτητής έχω επίγνωση των συνεπειών του Νόμου περί λογοκλοπής και δηλώνω υπεύθυνα ότι είμαι συγγραφέας αυτής της Διπλωματικής Εργασίας, έχω δε αναφέρει στην Βιβλιογραφία μου όλες τις πηγές τις οποίες χρησιμοποίησα και έλαβα ιδέες ή δεδομένα. Δηλώνω επίσης ότι, οποιοδήποτε στοιχείο ή κείμενο το οποίο έχω ενσωματώσει στην εργασία μου προερχόμενο από Βιβλία ή άλλες εργασίες ή το διαδίκτυο, γραμμένο ακριβώς ή παραφρασμένο, το έχω πλήρως αναγνωρίσει ως πνευματικό έργο άλλου συγγραφέα και έχω αναφέρει ανελλιπώς το όνομά του και την πηγή προέλευσης.

Ο φοιτητής
(Ονοματεπώνυμο)

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Υπογραφή

ABSTRACT

Due to the energy crisis which will come soon due to declining of oil reserves, required energy design of buildings with alternative energy sources, e.g. RES. In this diploma thesis we will examine an existing small hotel complex situated in Zakynthos, in order to be proposed ways to reduce its energy cost, intervening in the building envelope and installing a P/V System.

The development of the subject becomes in four Chapters. In the first chapter is studied this building with a systematic process of adapting the building at the local climatic conditions of Zakynthos. This can be done with the integration of climate data of Zakynthos, identified by the air temperature and relative humidity, at Olgyay's & Givoni's Bioclimatic Charts.

In the second chapter it is calculated the mean Coefficient of Thermal Transmittance of the building according to the «Κανονισμό Ενεργειακής Απόδοσης Κτηρίων» – K.Ev.A.K. (ΦΕΚ 407/9.4.2010) and is done a proposal for energy upgrade of the building, so that the mean Coefficient of Thermal Transmittance of the building to be smaller or equal to the mean Coefficient of Thermal Transmittance that defined by K.Ev.A.K.

In the third chapter it becomes study for the installation of a PV System at the small hotel complex in order to be covered the major part of its electrical loads for a period of 20 years, which is the minimum value of useful operating time of the PV System. All of the energy produced by the PV System will be given to PPC for its immediate utilization. While, the energy for the coverage of the electrical loads will be covered through PPC. Thus, it is avoided the possibility of not covering electrical loads on days with low solar potential and also it is greatly reduced the installation and maintenance costs of the PV System (smaller installed power, non-use of batteries). At the end of each year, it will be done offsetting of the energy generated by the PV System with the energy needs of the hotel complex, according to the program "*Net Metering*". It has also become an agreement with a neighboring company that when there is excess of electrical energy from the PV System, to be sold to that company at the same price with PPC.

Finally, in the fourth chapter it becomes an techno-economic study to see if the installation of the PV System is an advantageous investment considering many factors. More specifically, to see if the installation of the PV System is an advantageous investment, it is calculated the initial cost of installation and the amount of equity and foreign capital of the investment, the diachronic development of revenues of the investment, the diachronic development of the investment cost, the payback time of the investment, the diachronic change of the net profits of the investment (before taxes) at current and constant prices, the doubling time of the initial capital and the course of the economic efficiency of the investment.

The most important conclusions of this work are (a) because there is a degradation of performance of the photovoltaics 1% annually due to their ageing, there is also degradation of the energy generated by the P/V system. So, while at the 1^{st} year of operation of the PV System, it gives excess of energy of 10.2%, at the 2^{nd}

year of operation of the PV System there is a degradation of excess of energy of 1.2%. So, the PV module gives excess of energy of 9.0%. At the 10th year of operation of the PV System, it gives lack of energy of -0.5% and at the end of the 20th year of operation of the PV System, it gives lack of energy of -15.1%. In total in 20 years of operation of the PV module, which is the minimum value of useful operating time of PV System, it gives lack of energy just -1,5%. (b) The creation and operation of the PV System is clearly sustainable, since the payback time is much lower than twenty years, which is the minimum value of the useful operating time of the PV System. The payback time is at 5.35 years and subtracting from the expenses the participation of the government the final payback time of the investment is estimated at 3.55 years. In parallel, the investment can be characterized and financially attractive, particularly in the case of government funding, as the payback time is lower than the 1/5 of the lifetime of the installation. (c) Because the doubling time is less than twenty years, even not taking into account the government grant (9.00 years for current prices & 10.45 years for constant prices). So, the investment is not just sustainable but economically attractive.

CONTENTS

INTRODUCTION

In this diploma thesis we will examine an existing small hotel complex situated in Zakynthos in order to propose ways to reduce energy consumption with interventions in the building envelope and installation of a P/V System. Initially, it is studied the adjustment of an existing small hotel complex located in Zakynthos, to the local climatic conditions of Zakynthos with the help of Bioclimatic Charts of Olgyay & Givoni. Then followed calculation of the mean Coefficient of Thermal Transmittance of the building and it becomes a proposal for its energy upgrade. Subsequently, it became study for sizing of the P/V System to cover the electrical loads of the hotel complex, the calculation of the energy produced by this P/V System and the calculation of excess or lack of energy by this P/V System according to the electrical loads, the available solar potential and the ageing of the photovoltaics. Finally, it became an techno-economic study to see if the installation of the PV System is an advantageous investment considering many factors.

The importance of the inherent potential of the Renewable Energy Sources and their quality characteristic of being friendly to the environment guarantee, if rationally exploited and used, a world-wide oil-free economy, clean environment, development and sustainability. The fast development in engineering, materials science, chemistry and physics, information and communication technologies, and the continuous enrichment of the State of The Art on Renewable Energy Sources and Systems, offers the possibility for more efficient and effective applications with the integration of R.E.S. in every sector of life and economy.

In our time, this space age with the so many contrasts but also expectations for Quality of Life, 2 billion people, approximately 1/3 of the population of our planet, do not have access to electricity. If we examine the energy situation in developing countries, we find that less than 30% of their population has access to electricity grid.

The electricity, of course, it is not the only form of energy that require the human activities. Examining the amount of the total necessary energy we find that half the world's population is based for meet its energy needs in biomass, wood burning, although this type contribute only 7% of the energy consumed today. Neither by a long shot, thought for directly coverage of these needs by electricity.

As it has been calculated, the world's population since the 17th century, increased from 0.5 billion to 5.7 billion. Simultaneously, the energy consumption has increased 140 times over the same period. Specifically, from the 100 million tons of coal equivalent in the 17th century, we reached the period of 1997 to 14 billion tons of coal equivalent.

When the program of photovoltaic (PV) technology began organized globally and especially in the USA and Europe, 35 years ago, substantially there was no market for PV-applications except to specific cases and especially in space technology.

Unlike the situation prevailing 35 years ago concerning coverage of energy needs via PV generators, we find that in 1999 the PV generators worldwide sales exceeded the 200 MW, with broad applications in production, transports, agrarian economy and the residential sector.

The PV-generators are also used for the needs of meteorological measuring systems and other physical magnitudes and phenomena, electric lighting of region, parking etc.

The technology of PV seems to be an important dividend of the industry of the 21^{st} century. In the USA It estimated that by 2020 will have been sold PV frames of power $7 \cdot 10^9$ Watts with more than 3 billion Watts for the residential sector. In the year 2020 it is projected to have installed in total 7 GW_p of which 3 GW_p in the residential sector. Finally, it is predicted a significant reduction in the production cost of electricity.

1. CUSTOMIZING OF THE BUILDING IN LOCAL CLIMATE CONDITIONS

1.1 GENERALLY

In general, the selection of building passive thermal design strategies is based heavily on the local climatic conditions. Identifying suitable strategy for a given location can be made using bioclimatic charts. Olgyay's bioclimatic chart (Fig. 1.1), developed in the 1950's, was one of the early attempts to specify different zones at different combinations of relative humidity (as abscissa) and dry bulb temperatures (as ordinate) (Al-Azri et al., 2012).

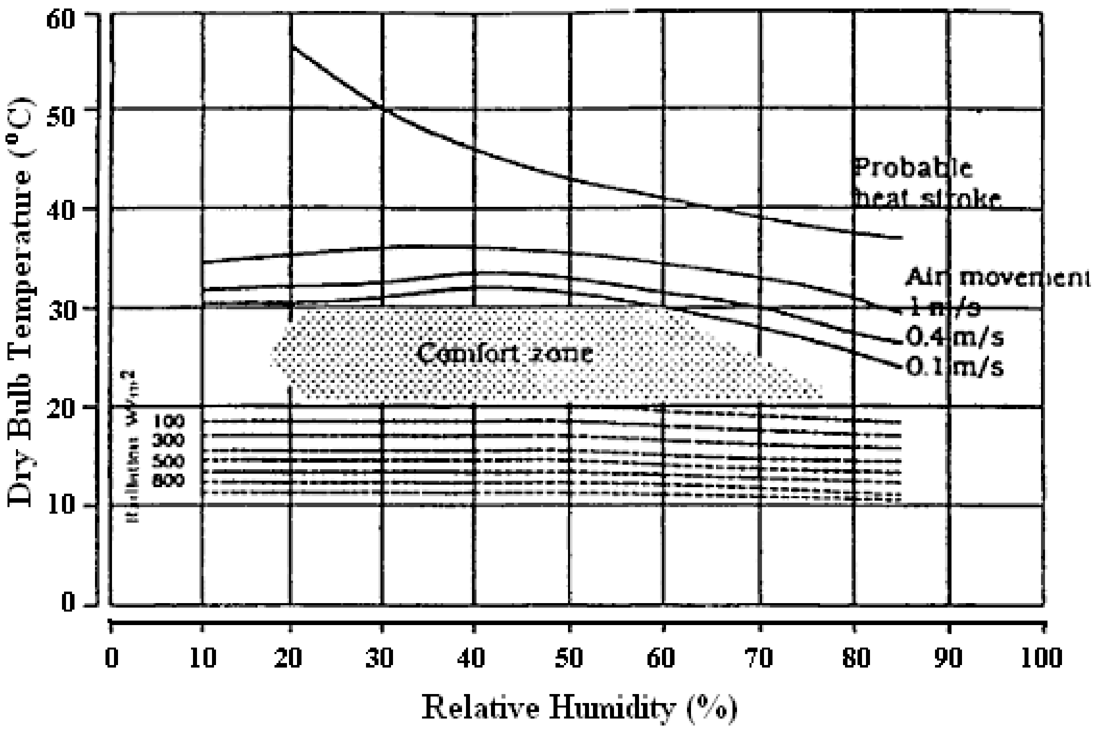


Figure 1.1: Olgyay's Bioclimatic Chart (Al-Azri et al., 2012)

Oglyay's chart has a constant comfort in the range from 20 to 30 °C. The level of comfort is applicable to indoor spaces with the indoor level of clothing. The comfort zone is shown at the center of Olgyay's chart. The chart takes into consideration levels of comfort that can be felt outside the comfort zone but in combination with ranges of other climatic factors such as mean radiant temperature, wind speed and solar radiation. Above the lower boundary of the zone shading is necessary to maintain reasonable level of comfort. Up to 10 °C below the comfort zone, comfort can be retained provided that there is enough solar radiation to offset the decrease in temperature. Likewise, to retain comfort up to around 10 °C above the zone, wind speed can offset the increase in temperature. Evaporative cooling according to this chart is another means to retain comfort at high temperature values but low humidity (Al-Azri et al., 2012).

Since Olgyay's chart only considers the outdoor conditions disregarding the indoors physiological considerations, it is only applicable for hot humid climates where there is minimal fluctuations between the indoors and the outdoors temperatures.

Another more popular bioclimatic chart is that of Givoni. This chart is based on the linear relationship between the temperature amplitude and vapor pressure of the outdoor air. Givoni's chart identifies the suitable cooling technique based on the outdoor climatic condition. Five zones are identified on Givoni's chart: thermal comfort, natural ventilation, high mass, high mass with night ventilation and evaporative cooling.

Bioclimatic charts are utilized by first identifying the average monthly condition. For each month, the average of the daily maximum temperature is calculated and matched with the average of the minimum daily absolute humidity to form the point (T_{max}, w_{min}). Likewise, the average of the daily minimum temperature is matched with that of the average daily maximum absolute humidity to form (T_{min}, w_{max}). The placement of the line segment connecting the two points will determine the proper passive cooling strategy for that month.

Givoni's chart (Fig. 1.2) is mainly applicable to residential and office buildings where heat gain is minimal. Modifications to Givoni's chart that suit nondomestic buildings can also be found in the literature. The natural ventilation zone on Givoni's chart assumes that the indoor mean radiant temperature and the vapor pressure are the same as those at outdoor conditions; an assumption that limits the application to buildings with medium to high thermal structure (Al-Azri et al., 2012).

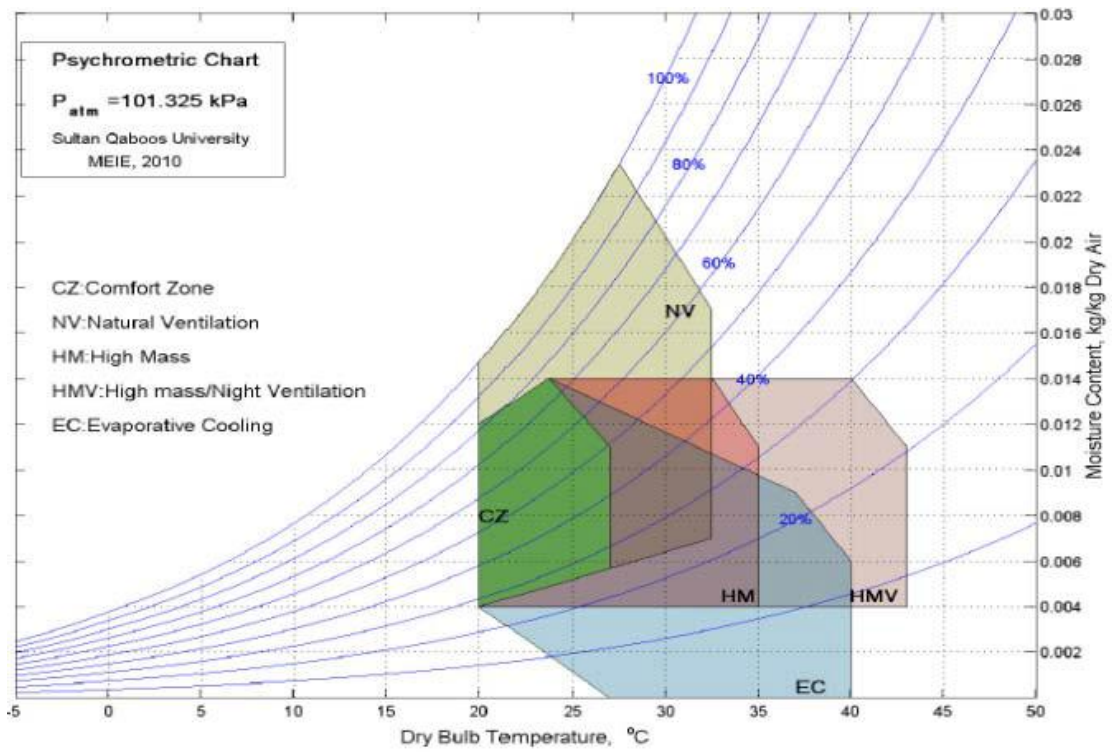


Figure 1.2: Givoni's Bbioclimatic Chart Plotted From Givoni's Chart Data (Al-Azri et al., 2012)

At high temperatures, mechanical air-conditioning is necessary to keep a habitable environment. On the left of the comfort zone (CZ), heating is needed to restore comfort using solar heating if the shift is slight but mechanical heating is necessary if the temperature is too low. The high thermal mass effect is provided by heavy construction that helps absorb heat that would be released overnight. If the weather is hot and dry, night ventilation will help releasing heat through windows, assisted by fans if necessary.

Using TMY weather data, bioclimatic chart for Muscat has been developed. The first step in the development of Givoni chart is the development of the background psychrometric chart for local conditions based on psychrometric relations (Al-Azri et al., 2012).

1.2 METHODOLOGY

As mentioned previously, Bioclimatic Charts are utilized by first identifying the average monthly condition. The Table 1 of Appendix I gives the maximum and minimum Dry Bulb Temperature (°C) and also the maximum and minimum Relative Humidity (%) per month for Zakynthos. The data are from the database "SODA".

For every month we need to find two points. The first point is at the intersection point of the maximum Dry Bulb Temperature (°C) and minimum Relative Humidity (%), (for January: 9,0 °C D.B.T. & 60% R.H.) and the second point is at the intersection point of the minimum Dry Bulb Temperature (°C) and maximum Relative Humidity (%), (for January: 1,5 °C D.B.T. & 71,5% R.H.). Finally, we unite these two points onto the Olgyay’s and Givoni’s Bioclimatic Charts. The same process is repeated and for the remaining months. See Graph 1 & 2 of Appendix I (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012).

1.2.1 Conclusions for Olgyay’s Bioclimatic Chart

Observing the Graph 1 of Appendix I we end up to the following conclusions. For the months of October, November, December, January, February, March, April and May the values of climate data are outside comfort conditions (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012).

For the months December, January and February, the addition of heat can’t be covered by the available solar radiation. The energy needs will be ensured by additional heating source. In our case study the additional heating source is air conditioning (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012).

For the months November, March and April, the addition of heat is necessary. A major part can be covered by the available solar radiation, with appropriate orientation of the building (southward), while the remaining part not covered by the sun, will be ensured by additional heating source (air conditioning). In our case study, the apartments already exist and have southwest orientation. See the floor plans of the building in Appendix V (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012).

The months of May and October the values of climate data are outside comfort conditions, but can be easily be approached by exploiting of the available solar radiation (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012).

For the months of June, July, August and September the climatic data fall within to a large extent in the comfort zone, on condition that will ensure solar protection of building openings. When the climate data are outside comfort conditions, they can be easily be approached by exploiting of the available solar radiation (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012).

1.2.2 Conclusions for Givoni's Bioclimatic Chart

The boundaries of the comfort zone determined by the dry bulb temperatures which fluctuate from 20-27 °C and the corresponding values of relative humidity from 27-82% (Al-Azri et al., 2012).

Observing the Graph 2 of Appendix I we end up to the following conclusions. For the months of October, November, December, January, February, March, April and May the values of climatic data do not fall within the boundaries of the comfort zone and we must determine the following requirements in order to approach the comfort zone. For the months of November, December, January, February, March and April (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012):

- Restriction of thermal losses
- Restriction of the penetration of air from the joints of frames
- Protection from cold winds
- Increase of solar gains, derived from the available solar radiation
- Supplementary heating, if the available solar radiation is insufficient

The months of May and October, the values of climate data are outside comfort conditions but close to the comfort zone. So, by defining the above requirements we set for the months November, December, January, February, March and April easily is approached the comfort zone (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012).

The months of June and September the values of climate data, to a large extent, are outside comfort conditions, but can be easily be approached by exploiting of the available solar radiation. When the values of the climatic data fall within the boundaries of the comfort zone, it should be ensured the possibility of sun protection of the openings (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012).

Finally, for the months of July and August the climatic data fall within to a large extent in the comfort zone, on condition that will ensure solar protection of building openings. In some cases the values of climate data may bilk from these boundaries. In case that the value of climate data are on the left and outside from the comfort zone (months of July and August), the comfort zone can be easily be approached by exploiting of the available solar radiation. In case that the values of climate data are on the right and outside from the comfort zone (month of August), we must determine the following requirements in order to approach the comfort zone (Ανδρεαδάκη, 2006 · Al-Azri et al., 2012):

- Sun protection of the openings
- High mass
- Natural ventilation
- Evaporating cooling

2. CALCULATION OF THE U_m OF THE BUILDING

2.1 GENERALLY

The calculation of the mean Coefficient of Thermal Transmittance (U_m) of the building was done according to the «Κανονισμό Ενεργειακής Απόδοσης Κτηρίων» – K.Ev.A.K. (ΦΕΚ 407/9.4.2010). In order to become the calculation of the mean Coefficient of Thermal Transmittance (U_m) of the building, are necessary some theoretical elements which are analyzed in Sections 2.1.1 and 2.1.2 which follow (T.O.T.E.E. 20701-2/2010, 2010).

2.1.1 Control stages of thermal insulating adequacy

The check of thermal insulating adequacy of the building is the first step of the energy study. It calculates the heat exchange of the building with the environment through conduction and convection and examine whether these confined within certain limits.

More particularly, the check is based on the coefficient of thermal transmittance (U) in two stages:

i. During the first stage is checked the thermal adequacy each of the individual structural elements of the building. To satisfy a structural element the requirements of thermal insulating protection of the regulation, it must the value of coefficient of thermal transmittance (U_{exam}) of this structural element not to exceed the value of maximum allowable coefficient of thermal transmittance (U_{max}) where defined by regulation, per climate zone for each category structural elements. I.e., it must apply:

$$U_{exam.} \leq U_{max} \qquad [W/(m^2 \cdot K)] \qquad (2.1)$$

During the second stage is checked the thermal adequacy of the whole building. To be satisfied the requirements of the regulation, it must the mean value of coefficient of thermal transmittance of the examined building (U_m) not to exceed the boundaries defined by the regulation for each building ($U_{m,max}$), included to one of the climatic zones of Greece. The maximum allowable value of coefficient of thermal transmittance ($U_{m,max}$) is calculated taking into account the ratio of total external surfaces of the building (vertical and horizontal) to volume (A/V). I.e., it must apply:

$$U_m \leq U_{m,max} \qquad [W/(m^2 \cdot K)] \qquad (2.2)$$

The satisfaction of these two checks is a prerequisite for the next steps of the energy study, as described in detail in the Technical Instruction «Detailed national specifications of parameters for the calculation of the energy performance of buildings and to issue the of energy performance certificate (T.O.T.E.E. 20701-1/2010, 2012)».

In case of the implementation of the energy study be used materials other than those prescribed in the study with the used materials.

2.1.2 Basic relationships

In the simplified assumption that flow of heat through a structural element is treated as one-dimensional size and in a direction perpendicular to the surface of the under consideration structural element. The exchange of heat are also considered independent of time (steady state) and unaffected by exogenous factors. Likewise, all structural materials are considered homogeneous and isotropic, with constant thermophysical characteristics and unaffected by changes in temperature.

Based on the above, the resistance that makes a homogeneous layer of a structural element to heat flow is calculated by the general relationship:

$$R = d/\lambda \qquad [(m^2 \cdot K)/W] \tag{2.3}$$

wherein:

R	$[(m^2 \cdot K)/W]$	the resistance to heat flow that makes the particular layer,
d	[m]	layer thickness,
λ	[W/(m·K)]	the coefficient of thermal conductivity of the material layer.

The total thermal resistance of all layers of a multilayer structural element, consisting of homogeneous material layers, defines the resistance of heat escape (R_Λ) and resulting from the sum of the individual resistances of each layer according to the generalized relationship:

$$R_\Lambda = \sum_{j=1}^{n} \frac{d_j}{\lambda_j} = \sum_{j}^{n} R_j \qquad [(m^2 \cdot K)/W] \tag{2.4}$$

The series of layers of a structural element practically, but affects the exploitation of the heat capacity.

- Placing the heat insulating layer in a position closest to the inner surface restricts the heat capacity of the structural element, i.e. its ability to store heat in its mass.
- Placing the heat insulating layer in a position closest to the external surface increases its heat capacity.

However, the heat capacity of the structural element decisively is influenced by its mass. The higher this, the greater the heat storage capability. The aim is the storable heat quantity, to be capable reallocate the inside environment of the building, when the space temperature drops at lower levels than the temperature of its mass.

The total thermal resistance that makes a multilayer structural element, consisting of homogeneous material layers, is defined by the sum of the resistances of the individual layers and the resistances of the air layer on either side of its faces according to the relationship:

$$R_{tot} = R_i + R_1 + R_2 + \cdots + R_n + R_a \qquad [(m^2 \cdot K)/W] \qquad (2.5)$$

wherein:

R_{tot}	$[(m^2 \cdot K)/W]$	the total resistance to heat flow that makes the structural element,
n	[–]	the plurality of layers of the structural element
R_i	$[(m^2 \cdot K)/W]$	the thermal transition resistance that makes the surface air layer in the transmission of heat from the interior space to the structural element
R_a	$[(m^2 \cdot K)/W]$	the thermal transition resistance that makes the surface air layer in the transmission of heat from the structural element to the interior space

The heat loss through a structural element defined by the coefficient of thermal transmittance (U), which gives the amount of heat transferred per unit time at constant temperature field through the unary surface of a structural element, when the air temperature difference on both sides of the structural element is equal to unit.

The coefficient of thermal transmittance of a structural element is defined by the relationship:

$$U = 1/R_{tot} \qquad [W/(m^2 \cdot K)] \qquad (2.6)$$

or according to the relationship 2.5, the general expression will be:

$$\frac{1}{U} = R_i + \sum_{j=1}^{n} R_j + R_a \quad [(m^2 \cdot K)/W] \qquad (2.7)$$

wherein:

U	$[W/(m^2 \cdot K)]$	the coefficient of thermal transmittance of the structural element
n	[–]	the plurality of layers of the structural element,
R_i	$[(m^2 \cdot K)/W]$	the thermal transition resistance that makes the surface air layer in the transmission of heat from the interior space to the structural element,
R_a	$[(m^2 \cdot K)/W]$	the thermal transition resistance that makes the surface air layer in the transmission of heat from the structural element to the interior space.

As the coefficient of thermal transmittance depends on the thicknesses of the layers of the structural element, and from the synagogue where presents with the air layers on either side of its faces, the increase or reduce of the thickness of a layer of material affects the coefficient of thermal transmittance of the structural element.

2.2 METHODOLOGY

Analytically the calculation of the mean Coefficient of Thermal Transmittance (U_m) of the building is shown in Appendix II, (T.O.T.E.E. 20701-1/2010, 2012 · T.O.T.E.E. 20701-2/2010, 2010 · T.O.T.E.E. 20701-3/2010, 2012). The mean Coefficient of Thermal Transmittance (U_m) was calculated and equals to (see Table 9.3 of Appendix II):

$$U_m = 2.890\ W/(m^2 \cdot K)$$

According to Figure 1 of Appendix II, Zakynthos is located to Climate Zone A. The total external surface (F) of the building is 960.23 m^2 and the total volume (V) of the building is 1583.54 m^3 (see Table 8 & 9 of Appendix II). So, the ratio F/V equals to:

$$F/V = 0.6m^{-1}$$

For Climate Zone A and ratio F/V=0.6m^{-1}, the maximum allowable mean Coefficient of Thermal Transmittance ($U_{m,max}$) of the building according to Table 1 of Appendix II equals to:

$$U_{m,max} = 1.03\ W/(m^2 \cdot K)$$

So, apply:

$$U_m > U_{m,max}$$

We observe that the mean Coefficient of Thermal Transmittance (U_m) of the building is greater than the maximum allowable mean Coefficient of Thermal Transmittance ($U_{m,max}$) of the building. For this reason, a proposal was made to the business owner, to upgrade the energy efficiency of the building by making some interventions in the building. The interventions that were proposed to be done are:

i. Addendum of expanded polystyrene in plates (d=50mm) at exterior masonries, at masonries with double shell, at exterior beam - brickwork – column and at tile roof. The thermal conductivity coefficient of expanded polystyrene in plates is λ = 0.033 W/(m·K).
ii. Replacement of existing aluminum frames with new aluminum frames with better energy efficiency.

In the old window frames, the glass pane and the frame have the following characteristics and coefficients of thermal transmittance (see Tables 3 & 4 of Appendix II):

a. Single glass pane → Ug = 5.70 W/(m2·K)
b. Metal frame without thermal break → U_f = 7.00 W/(m^2·K)

In the new window frames, that proposed to replace the old window frames, the glass pane and the frame have the following characteristics and coefficients of thermal transmittance (see Tables 3 & 4 of Appendix II):

a. Twins glass pane with air gap 12mm → U_g = 2.8 W/(m^2·K)
b. Metal frame with thermal break 24mm → U_f = 2.8 W/(m^2·K)

The calculation of the mean Coefficient of Thermal Transmittance (U_m) of the building, after its energy upgrade, was done analytically and in the same way as calculated for the existing situation of the building (see Appendix II), and equals to:

$$U_m = 0.995\ W/(m^2 \cdot K)$$

So, apply:

$$U_m < U_{m,max}$$

The proposed energy upgrade of the building, according to the owner, is planned to be implemented after 10 years due to financial difficulties. This is taken into account at PV-sizing. So, the PV System is sized to be able to cover the loads after 10 years, because most likely will not be applied the same power consumption after 10 years. E.g., the building will have been upgraded energy (new openings, insulation in walls, etc.), so the building will have less energy consumption. Also, in many cases, the apartments have periods not inhabited, so the building will have less energy consumption.

3. CONVENTIONAL PV SIZING

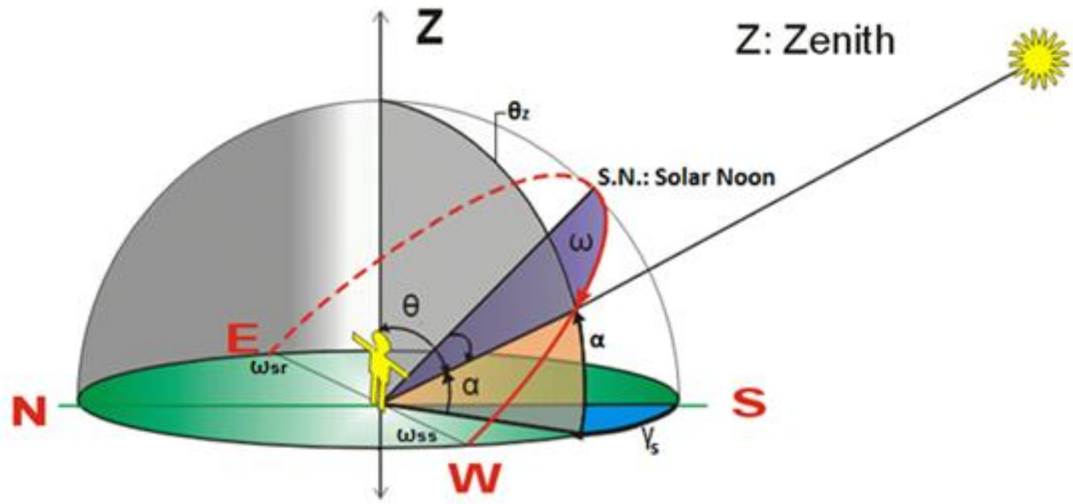
3.1 GENERALLY

In order to become the sizing of the PV System, are necessary some theoretical elements which are analyzed in Sections 3.1.1, 3.1.2 and 3.1.3 which follow (Kaplanis and Kaplani, 2013).

3.1.1 Geometrical and trigonometrical expressions concerning the solar trajectory and the estimation of solar intensity on any surface

The trajectory of the sun from the sunrise to sunset, as visualized from an observer on the horizontal, is presented in Figure 3.1. The solar noon, S.N. is the position of the sun that subtends the highest angle from the horizontal with respect to the observer. This point divides the sun trajectory into two equal parts, from sunrise to solar noon and from solar noon to sunset. At solar noon, the time is set at 12:00h, Solar Time, S.T. The following important angles are made clear in the frame below.

a. Declination angle, δ, of the Sun, Solar Time (S.T.), and Watch Time (W.T.).



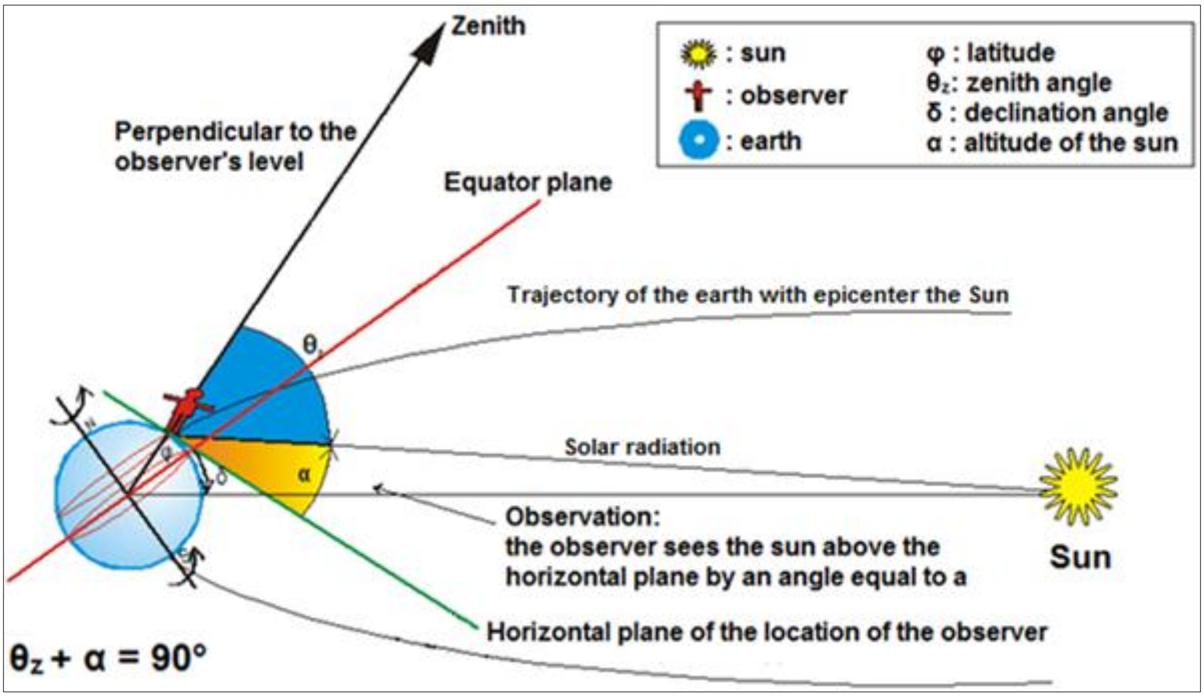
ω: angle hour. ω, changes by 360°:24h = 15 per hour.
$\omega<0$ before solar noon, $\omega>0$ after solar noon.
ω_{sr}: is the sunrise hour angle.
ω_{ss}: is the sunset hour angle.
α: altitude. γ_s: solar azimuth angle.
θ_z: zenith angle of the sun: It holds: $\alpha+\theta_z = 90°$.

Figure 3.1: This figure shows a daily trajectory of the sun. S.N. stands for the Solar Noon and there, we set the solar, (true), time at 12.00 hours. Then, the hour angle, ω, is 0°, (Kaplanis and Kaplani, 2013 · Καπλάνης, 2004)

The declination angle δ of the Sun, is the angular position of the sun at solar noon with respect to the plane of the equator, see Figure 3.2. It is the angle between Sun-Earth's center and the equator plane, δ is positive from Spring equinox (21.03) to Autumn equinox (22.09). Generally, holds: $-23.45° \le \delta \le +23.45°$.

Solar Time, (S.T.), is the time based on the apparent angular motion of the sun across the sky, with Solar Noon (S.N.), the time that the sun crosses the meridian of the observer. Therefore, solar time, (S.T.), is the time, which is measured according to the sun position, and the starting point is taken at Solar Noon, where, S.T.=12.00h. According to this, the hour angle, ω (negative in the morning, positive in the afternoon), which is the angular displacement of the sun east or west of the local meridian due to the rotation of the earth on its axis with 15° per hour, is measured from S.N. It increases every hour with 15° or needs 4 minutes per degree, due to its rotation. Hence:

$\omega=(15°/h)\cdot 24h=360°$, which is obvious. Finally, when $\omega=0°$, S.T. is 12.00 h.



Note: 1. The observer watches the sun over the horizontal surface at an angle, a, and altitude, as represented in the above figure, 2. The figure above corresponds to the winter period for the North Hemisphere: the sun lies below the equator plane, 3. In Figure 3.2, δ has a negative value, as it presents a winter configuration.

Figure 3.2: Schematic presentation of the sun, the earth, the site and its horizontal surface for better understanding of the angles: δ (sun declination), θ_z (azimuth angle), α (altitude of the sun), (Kaplanis and Kaplani, 2013 · Καπλάνης, 2004)

δ, changes from -23.45° in Winter solstice (22nd of December) up to +23.45° in Summer solstice (22nd of June).

δ=0, in Equinox (21st of March and 23rd of September), according to the formula known as Cooper formula, given below.

$$\delta = 23{,}45^o \cdot sin\left(360 \cdot \frac{284+n}{365}\right) \quad (3.1)$$

where n, is the day of the year counted from the 1st of January. For example let us take the 1st of April: n=31+28+31+1=91. Between S.T. and clock time holds the relationship:

$$S.T. = W.T. - 4\frac{min}{degree} \cdot (L_{st} - L_{loc}) + E \tag{3.2}$$

wherein:

W.T.: Watch Time, which is conditioned by the Greenwich meridian, and the summer or winter conditioned time
L_{st}: is the standard meridian for the local time zone
L_{loc}: is the longitude of the location in question in degrees
E: is the equation of time

Convention: L is measured towards East, as positive. E is estimated by the expression:

$$E = 229{,}2 \cdot (0{,}000075 + 0{,}001868 \cdot cos\,B - 0{,}032077 \cdot sin\,B \\ -0.014615 \cdot cos(2 \cdot B) - 0{,}04089 \cdot sin(2 \cdot B)) \tag{3.3}$$

wherein:

$$B = \frac{(n-1) \cdot 360}{365} \tag{3.4}$$

Table 3.1: Some typical dates and declinations, δ, values (Kaplanis and Kaplani, 2013 · Καπλάνης, 2004)

Declination (δ)	Date
+23.27°	22 June
+20°	21 May, 24 July
+15°	1 May, 12 August
+10°	16 April, 28 August
+5°	3 April, 10 September
0°	21 March, 22 September
-5°	8 March, 6 October
-10°	23 February, 20 October
-15°	9 February, 3 November
-20°	21 January, 22 November
-23.27°	22 December

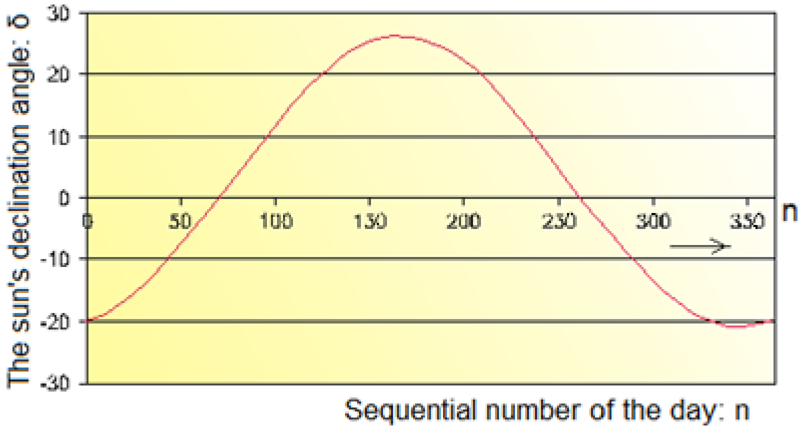
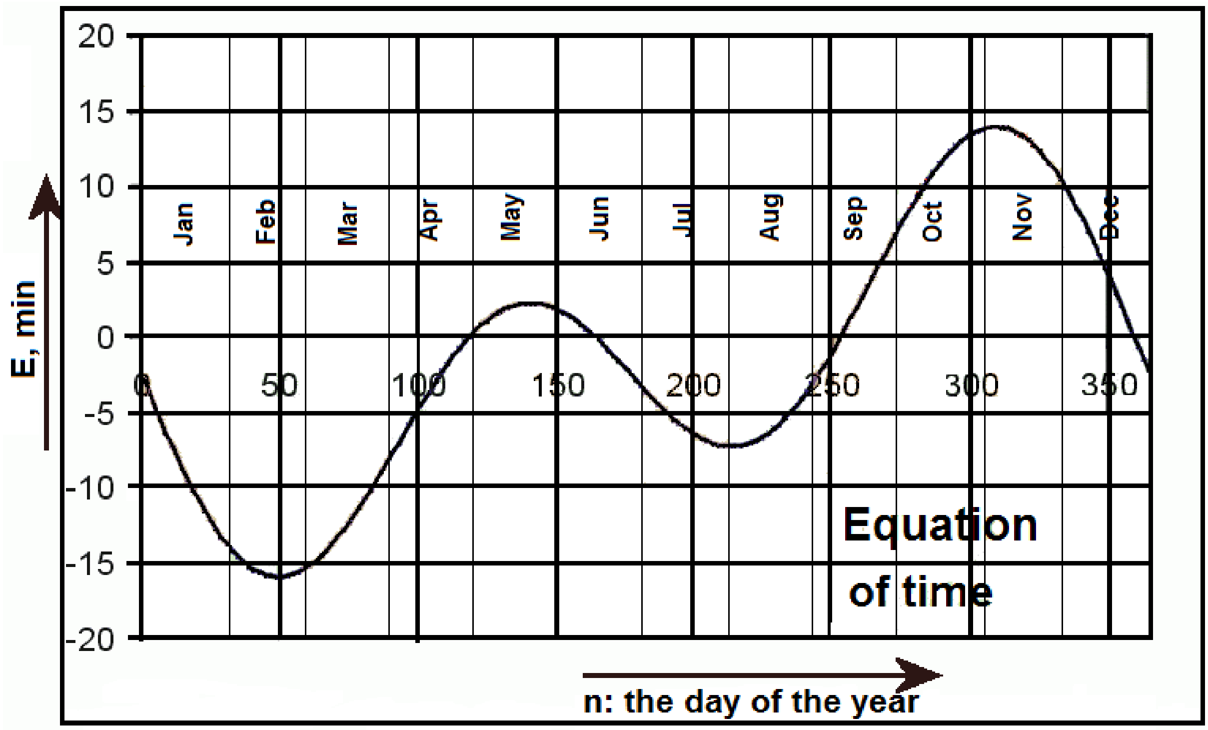


Figure 3.3: The curve gives values of the sun's declination angle, δ as a function of the day, n, of the year, (Καπλάνης, 2004)

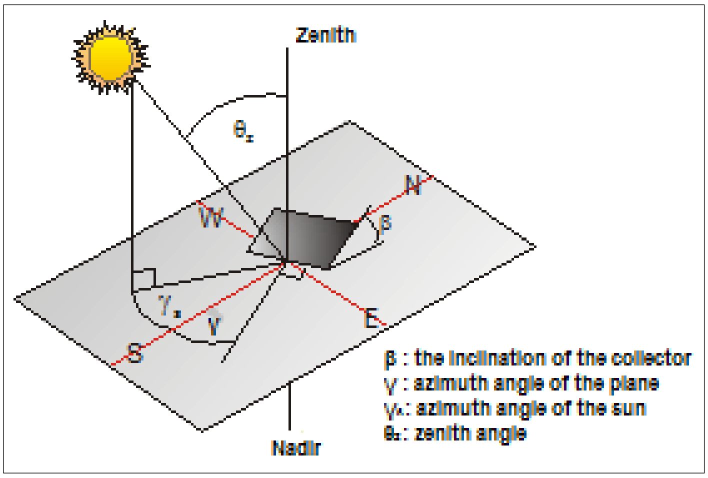


Note: In solar studies the time used is the Solar Time, unless differently specified.

Figure 3.4: The equation of time, E, in minutes, as a function of day of the year, (Kaplanis and Kaplani, 2013 · Καπλάνης, 2004)

b. Important formulae between solar trajectory angles, spherical trigonometer.

Let's consider a flat plate solar collector or a PV panel placed to the horizontal with an angle β to horizontal and with an azimuth angle γ, see Figure 3.5, in a region with latitude φ.



Note: Understand the difference between γ and γ_S. γ is the azimuth angle of the plane. This is the angle between the projection to the horizontal of the normal to the plane on one hand and the direction North-South on the other. γ_S is the azimuth of the Sun shown in Figure 3.1, too.

Figure 3.5: A configuration of important angles between the sun's beam and an inclined plane, (Kaplanis and Kaplani, 2013 · Καπλάνης, 2004)

Task: Determine the angle of incidence, θ, of the sun's direct beam on the solar collector or PV-panel for any day η and any time h, which is directly related, to ω. Also, the same when the Sun is at solar noon (S.T.=12.00 and ω = 0°).

The general equation, which relates the angle of incidence, θ, to the plane and the other angles, is the following:

$$\cos\theta = \sin\delta\cdot\sin\varphi\cdot\cos\beta - \sin\delta\cdot\cos\varphi\cdot\sin\beta\cdot\cos\gamma \\ +\cos\delta\cdot\cos\varphi\cdot\cos\beta\cdot\cos\omega \\ +\cos\delta\cdot\sin\varphi\cdot\sin\beta\cdot\cos\gamma\cdot\cos\omega + \cos\delta\cdot\sin\beta\cdot\sin\gamma\cdot\sin\omega \qquad (3.5)$$

Notice: when β=0°, then θ=θ_z and for γ=0°, south facing, the above equation becomes:

$$\cos\theta_z = \cos\delta\cdot\cos\varphi\cdot\cos\omega + \sin\varphi\cdot\sin\delta \qquad (3.6)$$

The altitude of the sun (α) is determined by the eq. (3.7):

$$a + \theta_z = 90^{\circ} \qquad (3.7)$$

The solar azimuth angle (γ_S), is given by the relationship:

$$\gamma_s = \frac{\cos\delta\cdot\sin\omega}{\sin\theta_z} \qquad (3.8)$$

When a surface faces the South, γ=0°, then the eq. (3.5) becomes:

$$\cos\theta = \cos(\varphi-\beta)\cdot\cos\delta\cdot\cos\omega + \sin(\varphi-\beta)\cdot\sin\delta \qquad (3.9)$$

When β = 90°, then the eq. (3.5) becomes:

$$cos\,\theta = -sin\,\delta \cdot cos\,\varphi \cdot cos\,\gamma + cos\,\delta \cdot sin\,\varphi \cdot cos\,\gamma \cdot cos\,\omega + cos\,\delta \cdot sin\,\gamma \cdot sin\,\omega \quad (3.10)$$

Determine the angle β for normal incidence, θ=0°, of the sun's direct beam to a tilted PV-panel or onto a solar collector, during the solar noon, ω=0°, the eq. (3.5) becomes:

$$cos\,\theta = cos(\varphi - \beta) \cdot cos\,\delta \cdot cos\,\omega + sin(\varphi - \beta) \cdot sin\,\delta =>$$
$$cos\,\theta = cos(\varphi - \beta) \cdot cos\,\delta \cdot 1 + sin(\varphi - \beta) \cdot sin\,\delta =>$$
$$cos\,\theta = cos[(\varphi - \beta) - \delta] =>$$
$$\theta = (\varphi - \beta) - \delta \quad (3.11)$$

Hence, for normal incidence of the sun beam, that is θ=0, at S.N. holds β=φ-δ.
To determine the angle of the sunset or sunrise, set θ_z=90° or α=0° in eq. (3.6) which now becomes (see Fig. 3.1):

$$\cos \omega_s = -\tan \varphi \cdot \tan \delta => \omega_s = \cos^{-1}(-\tan \varphi \cdot \tan \delta) \quad (3.12)$$

ω_s: is the sunset hour angle, in degrees or radians, at horizontal.
The sunset hour angle, ω_s', for an inclined surface, is given by the relationship below:

$$\omega_s' = min[\omega_s, cos^{-1}(-tan(\varphi - \beta) \cdot tan\,\delta)] \quad (3.13)$$

where, ω_s' is the smaller value between the ω_s and the value calculated by:

$$cos^{-1}(-tan\,\varphi \cdot tan\,\delta) \quad (3.14)$$

It is very important for any application to know if and when a solar collector or a PV panel is shaded/shadowed. Therefore, solar charts the correct tool for that and several types of software are used. However, the engineer must understand and deal with this issue by using principles and the right formula. The question is how far from each other should the PV arrays or solar collectors be placed in order not to shade/shadow the series of panels; see Figure 3.6. In fact, they require non-shadowing all year long. In this case, we must find the lowest position of the sun with respect to the horizon during the solar noon. This is determined by ω=0° to eq. (3.6). Then, the result easily obtained is:

$$\theta_z = \varphi - \delta = 90° - \alpha \quad (3.15)$$

and as the sun takes its lowest position in the Winter solstice, δ=-23.45° and finally the sun altitude for the 22nd of December is:

$$\alpha = 90° - \varphi + \delta \quad (3.16)$$

In practice, this α value is the lowest angle a series of PV panels "sees" the one in front. Then, the question that raises is what is the inclination β to horizontal that the PV arrays or the solar collectors are fixed at. The answer is conditioned on the maximization of the solar radiation on the PV array/solar collectors throughout the year. Special software on this issue exist. For countries with latitude around 35°-40°, β is evaluated around 25°-30°.

The shortest distance between arrays not to be shaded by the one infront can be determined based on the law of triangles in Geometry, which implies that:

$$\frac{sin(180-\beta-\alpha)}{D}=\frac{sin\big(180-\beta-(90-\theta_z)\big)}{D}=\frac{sin(\alpha)}{L}=\frac{sin(90-\theta_z)}{L} \quad (3.17)$$

$$D=L\cdot\frac{cos(\beta-\theta_z)}{cos(\theta_z)} \quad or \quad D=L\cdot\frac{sin(\beta+\alpha)}{sin(\alpha)} \quad (3.18)$$

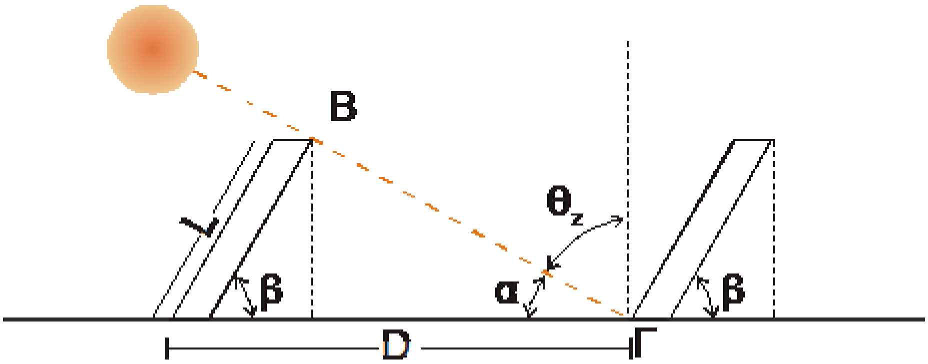


Figure 3.6: Series of PV arrays or solar collector panels positioned one after the other in a plant with inclination β. L is the width of the array that depends on the design of the PV arrays and the type of PV panels to be used. The arrays face south, (Kaplanis and Kaplani, 2013 · Καπλάνης, 2004)

3.1.2 Formulae to calculate the quantities and parameters required for the estimation of global intensity on the inclined plane, I_T, and daily global solar radiation on an inclined plane, H_T

The nomenclature used has as follows:

H and $\overline{H}$: Daily and mean monthly daily global solar radiation at horizontal [kWh/m^2] or [MJ/m^2].

H_d and $\overline{H}_d$: Daily and mean monthly daily diffuse solar radiation at horizontal [kWh/m^2] or [MJ/m^2].

H_b and $\overline{H}_b$: Daily and mean monthly daily direct solar radiation at horizontal [kWh/m^2] or [MJ/m^2].

T_a: ambient temperature [°C].

The following quantities should be determined in order to estimate the solar radiation, H_T, at any surface.

i. H_{ext}, which is the daily extraterrestrial solar radiation determined by the relationship:

$$H_{ext}(n) = \frac{24 \cdot 3600}{\pi} \cdot I_{sc} \cdot \left[1 + 0.033 \cdot cos\left(\frac{360 \cdot n}{365}\right)\right]$$
$$\cdot \left[cos(\varphi) \cdot cos(\delta) \cdot sin(\omega_s) + \frac{\pi \cdot \omega_s}{180} \cdot sin(\varphi) \cdot sin(\delta)\right] \quad (3.19)$$

where, I_{sc} = 1353 W/m^2

Notice: in the above equation ω_s is in degrees; if it was in radians the term π/180 would not appear.

ii. An estimation of the monthly extraterrestrial radiation, E_{ext}(mo), may be obtained using the above formula for the mean day n of the month or the representative day of the month: 17 Jan, 15 Feb, 16 Mar, 15 Apr, 15 May, 11 Jun, 17 Jul, 16 Aug, 16 Sep, 16 Oct, 15 Nov, 11 Dec. Then, the result is multiplied by the number of days of the month.

More accurately, the monthly extraterrestrial radiation, E_{ext}(mo), can also be calculated by the expression:

$$E_{ext}(mo) = \sum_{n=1}^{N} H_{ext} \quad (3.20)$$

where, N is the number of days of the month; ω_s and δ are determined as in Section 3.3.1 and generally depend on the day.

iii. $\overline{\mathrm{K}}_{\mathrm{T}}$, the monthly average daily clearness index: $\overline{\mathrm{K}}_{\mathrm{T}} = \overline{\mathrm{H}}/\overline{\mathrm{H}}_{\mathrm{ext}}$, $\overline{\mathrm{H}}$ may be obtained by any national, local or international databases for the mean day of the month, while for $\overline{\mathrm{H}}_{\mathrm{ext}}$ its estimation was given above.

iv. $\overline{\mathrm{H}}_{\mathrm{d}}/\overline{\mathrm{H}}$ to be determined using data from the above data bases or as to be outlined later.

v. R_b the ratio of the beam solar Intensity on a tilted surface I_{bn} to the corresponding one on a horizontal surface I_b. Hence, by definition the conversion from horizontal to the inclined for the beam solar intensity is: $R_b = I_{bn}/I_b$.

Using the trigonometry and the Figures below, which provide the intensity on the horizontal and on the inclined through their normal and the tangential to the plane components, it finally comes out that:

$$R_b = \frac{cos(\theta)}{cos(\theta_z)} \quad (3.21)$$

From the components of the solar intensity on the horizontal (I_b, I_{par}) and on the inclined plane (I_{bn}, I_{par}), we may determine the ratio R_b.

$$R_b = \frac{I_{bn}}{I_b} = \frac{I_{bd} \cdot cos(\theta)}{I_{bd} \cdot cos(\theta_z)} = \frac{cos(\theta)}{cos(\theta_z)} \quad (3.22)$$

This is the instant R_b and it is derived by the short analysis, in Figure 3.7.

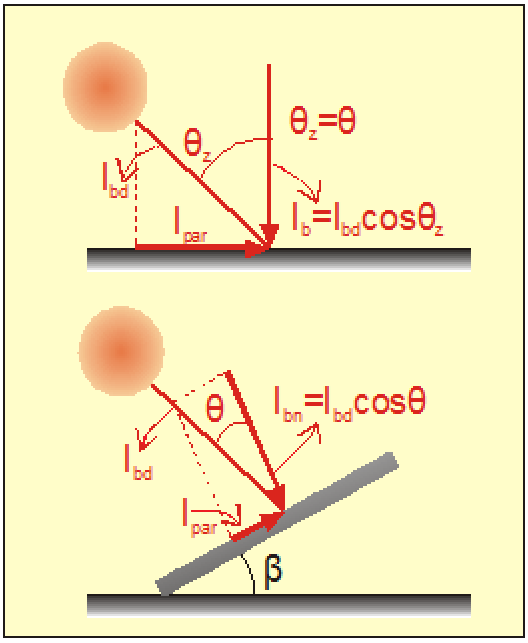


Figure 3.7: A presentation of the direct beam components at horizontal and at the inclined plane in order to drive the expression for the conversion coefficient, R_b, (Kaplanis and Kaplani, 2013 · Καπλάνης, 2004)

Substituting cosθ and $\cos\theta_z$ from eq. (3.9) and eq. (3.9), and for γ = 0°, we get:

$$R_b = \frac{I_{bn}}{I_b} = \frac{I_{bd} \cdot cos\,\theta}{I_{bd} \cdot cos\,\theta_z} = \frac{cos\,\theta}{cos\,\theta_z} = \frac{cos(\varphi - \beta) \cdot cos\,\delta \cdot cos\,\omega + sin(\varphi - \beta) \cdot sin\,\delta}{cos\,\varphi \cdot cos\,\delta \cdot cos\,\omega + sin\,\varphi \cdot sin\,\delta} \tag{3.23}$$

Finally, the conversion coefficient for the intensity of the global solar radiation from the horizontal to inclined plane, is given by the expressions:

$$R = \frac{I_T}{I} = \frac{I_b}{I} \cdot R_b + \frac{I_d}{I} \cdot \left(\frac{1 + cos\,\beta}{2}\right) + r \cdot \left(\frac{1 - cos\,\beta}{2}\right) \tag{3.24a}$$

$$R = \frac{I_T}{I} = \left(1 - \frac{I_d}{I}\right) \cdot R_b + \frac{I_d}{I} \cdot \left(\frac{1 + cos\,\beta}{2}\right) + r \cdot \left(\frac{1 - cos\,\beta}{2}\right) \tag{3.24b}$$

where, r, is the reflection coefficient of the surroundings that the solar collector is placed. This is the relationship of Liu and Jordan, to determine R assuming it consists of the beam direct radiation, the diffuse and the reflected and that the diffuse is isotropically spread around.

r ≈ 0.2 in usual ground conditions
r ≈ 0.7 for snow-covered areas

On the other hand, the monthly mean value of R_b is calculated by the mean monthly daily value of R_b:

$$\bar{R}_b = \frac{cos(\varphi - \beta) \cdot cos\,\delta \cdot sin\,\omega_s' + (\pi/180) \cdot \omega_s' \cdot sin(\varphi - \beta) \cdot sin\,\delta}{cos\,\varphi \cdot cos\,\delta \cdot sin\,\omega_s + (\pi/180) \cdot \omega_s \cdot sin\,\varphi \cdot sin\,\delta} \tag{3.25}$$

ω_s', ω_s are determined, as in Section 3.1.1.

3.1.3 Estimation of the available solar radiation in a place

One should study the above section in order to proceed to the appropriate calculations for the hourly, daily and monthly solar radiation on any surface with any inclination and orientation. The methodology to determine the mean daily solar radiation on any surface is to be analyzed here after.

Definition:

Clearness Index K_T has to be determined for every month or any day. $\bar{K}_T$ is the ratio of the monthly or mean monthly daily solar energy at horizontal, $\bar{H}$, in a site, over the solar energy for the same period at extra-terrestrial, H_{ext}, for the latitude of the site:

$$\bar{K}_T = \bar{H}/H_{ext} \tag{3.26}$$

$\bar{H}$ may be obtained by a proper data base.

The reflectivity, r, for an area with dry climate is 0.2, whilefor sites with more green and snow r takes up higher values. Generally, r lies in the range 0.2÷0.7.

The sun declination angle, δ, is determined by the equation:

$$\delta = 23{,}45^o \cdot sin\left(360 \cdot \frac{284 + n}{365}\right) \tag{3.27}$$

δ values are the same for any place in the earth, δ values depend only on the typical (mean) day of the each month, as provided in Section 3.1.2.

The sunset hour angle, ω_s, on a horizontal surface for the typical day of each month is given by the equation:

$$\omega_s = cos^{-1}(-tan\varphi \cdot tan\delta) \tag{3.28}$$

where φ is the site's latitude.

According to Duffie J. and Beckman W (1991), the $\bar{H}_d/\bar{H}$ ratio, i.e. the diffuse solar radiation over the total (global) one, is given by eq. (3.29). It is related with the clearness index $\bar{K}_T$, according to the equation:

$$\frac{\bar{H}_d}{\bar{H}} = \begin{cases} 0.99 & \bar{K}_T \le 0.17 \\ 1.188 - 2.272\bar{K}_T + 9.473\bar{K}_T^2 - 21.865\bar{K}_T^3 + 14.648\bar{K}_T^4 & 0.17 < \bar{K}_T < 0.75 \\ -0.54\bar{K}_T + 0.632 & 0.75 \le \bar{K}_T < 0.80 \\ 0.2 & \bar{K}_T \ge 0.80 \end{cases} \tag{3.29}$$

$\overline{\mathrm{H}}_{\mathrm{d}}/\overline{\mathrm{H}}$: mean monthly daily diffuse solar radiation on horizontal global over the global solar radiation at the site for the same period of the year. Remark: If the monthly average daily solar radiation on the horizontal were not available, we might estimate it, using eq (3.26), by the extraterrestrial insolation (H_{ext}) and the clearness index $\overline{\mathrm{K}}_{\mathrm{T}}$, values, if $\overline{\mathrm{K}}_{\mathrm{T}}$, were provided from a database.

H_{ext}, is the integral (global) daily extraterrestrial radiation on the horizontal surface, determined as follows:

$$H_{ext}(n) = \frac{24 \cdot 3600}{\pi} \cdot I_{sc} \cdot \left[1 + 0.033 \cdot cos\left(\frac{360 \cdot n}{365}\right)\right] \cdot \left[cos(\varphi) \cdot cos(\delta) \cdot sin(\omega_s) + \frac{\pi \cdot \omega_s}{180} \cdot sin(\varphi) \cdot sin(\delta)\right] \quad (3.30)$$

As said, the values of the global solar radiation, H, on the horizontal can be calculated using the following formula, in case H is not available in any database.

$$\overline{H} = \overline{K}_T \cdot \overline{H}_{ext} \quad (3.31)$$

while, K_T on the other hand, might have been tabulated, due to its importance.

The next step is to calculate R_b i.e. the conversion coefficient of the beam solar insolation from the horizontal to the inclined plane.

$$R_b = \frac{I_{bn}}{I_b} = \frac{solar\ beam\ (direct) on\ a\ tilted\ plane}{solar\ beam\ (direct)\ on\ horizontal} \quad (3.32)$$

$$I_{bn} = R_b \cdot I_b \quad (3.33)$$

However, the task is to determine the mean monthly values of the solar radiation at any surface and not the instant I_T value on a plane. Therefore, the mean monthly R values must be determined, where:

$\overline{\mathrm{R}}_{\mathrm{b}}$ is the mean monthly value of R_{b}.

$\overline{\mathrm{R}}_{\mathrm{b}}$ is function of the site's latitude, φ, the panel's slope, β, and the sunset hour angle, ω_s', on a tilted surface, according to:

$$\overline{R}_b = \frac{cos(\varphi - \beta) \cdot cos\,\delta \cdot sin\,\omega_s' + (\pi/180) \cdot \omega_s' \cdot sin(\varphi - \beta) \cdot sin\,\delta}{cos\,\varphi \cdot cos\,\delta \cdot sin\,\omega_s + (\pi/180) \cdot \omega_s \cdot sin\,\varphi \cdot sin\,\delta} \quad (3.34)$$

The sunset hour angle, ω_s', to the inclined plane is given by the equation:

$$\omega_s' = min[cos^{-1}(-tan\,\varphi \cdot tan\,\delta), cos^{-1}(-tan(\varphi - \beta) \cdot tan\,\delta)] \quad (3.35)$$

that is, ω_s' is the lower value of the two angles:

$$\omega_s'\ and\ cos^{-1}(-tan\,\varphi \cdot tan\,\delta)$$

The ratio, $\overline{\mathrm{R}}$, of the monthly average daily total radiation on a tilted surface, β, over that on a horizontal surface is determined by equation:

$$\bar{R} = \frac{\bar{H}_T}{\bar{H}} = \left(1 - \frac{\bar{H}_d}{\bar{H}}\right) \cdot \bar{R}_b + \frac{\bar{H}_d}{\bar{H}} \cdot \left(\frac{1 + cos\,\beta}{2}\right) + r \cdot \left(\frac{1 - cos\,\beta}{2}\right) \quad (3.36)$$

Correspondingly, the conversion factor R for any instant or hour is written $R=I_T/I$. Finally, the average daily total radiation on a sloped surface, is equal to:

$$\bar{H}_T = \bar{H} \cdot \bar{R} \quad (3.37)$$

The annual solar radiation E(an) is estimated by:

$$E(an) = \sum_{mo} \bar{H}(n; mo) \cdot \bar{R}(n; \beta; mo) \cdot N(mo) \quad (3.38)$$

where n is the representative day of the month. R(n; β; mo) is the conversion factor from the horizontal to the inclined plane for an angle β for the representative day of the month. N(mo) is the number of the days of the month.

The sum of the product of the solar radiation on the horizontal for the representative day of the month, multiplied by the R conversion factor and the number of days N of the month provides E(an). We then change β and repeat till we determine the value of the angle that maximizes E(an).

Definition: Peak Solar Hour (PSH)

For convenient calculations concerning the Power and the Energy delivered during a day by a PV-generator, one defines the Peak Solar Hour (PSH).

To make this term understood, let us take Figure 3.8, which shows the global solar intensity on the horizontal in Patra, Greece during the 14th of July of the year 2012. One may easily notice that the intensity at horizontal is always less than 10^3 W/m^2, during that day. To estimate the pragmatic efficiency and the power delivered by a PV panel, one should normalize the solar intensity to 10^3 W/m^2, due to the S.T.C. convention. PSH is thus defined as the time length in hours/day for a given day, under the assumption that the solar intensity will be kept constant at 10^3 W/m^2 during this time length; the PSH value should be such that the solar energy per day, H, estimated according to the above assumption, which is H=10^3 W/m^2·(PSH) h/day, is equal to the pragmatic case, i.e. the one that is obtained by the integration of the area under the curve in Figure 3.8. This statement is explained graphically below.

Note:

PSH is a number in hours/day equal to the daily energy (global solar radiation at horizontal), in the place of concern, expressed in kWh/m^2.

The figure in the above analysis holds for the horizontal. However, when we analyze inclined PV-panels or solar collectors, we have to convert the solar radiation to the inclined plane. This is done by multiplying I_h (solar intensity) at horizontal or $\bar{H}_h$ (daily energy) at horizontal by the factor R or $\bar{R}$, respectively. $\bar{R}$, is a conversion factor converting H_h to H_T on the inclined PV-panel. $\bar{R}$, is a function of φ (latitude), inclination to horizontal (β), and the month.

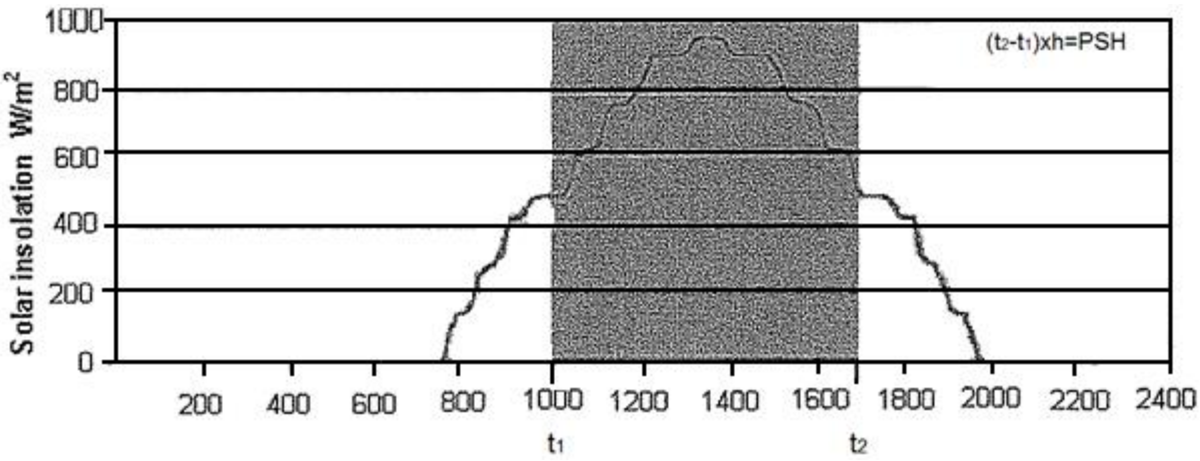


Figure 3.8: Global Solar insolation at horizontal at Patra, Greece (14.07.2012). The shadowed area has energy units; having as one side the P.S.H and height equal to 10^3W/m^2.The energy it represents is equivalent to the surface under the curve, which represents the intensity of the global solar radiation, (Kaplanis and Kaplani, 2013)

The energy produced by a PV generator with the same peak power P_m in a day may be given by the following equation:

$$E_{pv} = H(n) \cdot R(n;\beta) \cdot A_{pv} \cdot \eta_{pv} = P_m \cdot PSH \cdot R(n;\beta) \quad (3.39)$$

where, η_{pv} is the efficiency of the PV modules, A_{pv} is the total area of the PV array or H the solar radiation data, in kWh/m^2/day, for the horizontal and the conversion factor R for the mean monthly value. E_{pv} can be easily estimated, as in eq. (3.39) by the peak power of the PV generator, the PSH of the mean day of the month and the conversion factor for the angle of inclination the PV array will be mounted on for the support frame.

Remark: The stochastic behavior of the solar radiation is an opposing factor to predetermine the solar energy at a place in a day or a month to cost-effectively design or size a power production plant. Therefore, we may work on average values or on more sophisticated statistics and techniques to size PV or solar plants.

3.2 SIZING OF THE PV GENERATOR USING THE WH METHOD

According to Kaplanis and Kaplani (2013) and Καπλάνης (2004), the sizing of the PV System will be done as following. The apartments have the following daily non-critical loads per month:

Table 3.2: Daily non-critical loads per month

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q_L [KWh/day]	101	143	110	68	56	111	129	129	63	82	122	98

Annual Average: 101 KWh/day

Step 1

December is the most unfavorable month. According to this month will become the PV-sizing. The mean monthly daily temperature of the PV is calculated from the following relationship:

$$T_{pv} = T_a + \lambda \cdot I_T \qquad [℃] \qquad (3.40)$$

T_a is the mean monthly daily ambient temperature. T_a is taken from the database PVGIS and is equal to 14.3°C for December. (see Graph 5c of Appendix III).

λ = 0.01 (for strong wind conditions) ÷ 0.035 (for mild wind conditions)

I is the mean value of the hourly solar radiation at horizontal where observed from the hourly data of the years 2004 & 2005 from the database SODA for the month of December (see Graph 5a of Appendix III). It is selected the maximum value of the two years 2004 & 2005 (worst case):

$$I = 134\, W/m^2$$

For β = 25° and γ = 0°:

$$I_T = 155\, W/m^2$$

So, from eq. (3.40):

$$T_{pv} = 14.3℃ + 0.03 \cdot 155\, W/m^2 = \mathbf{18.96}℃$$

Step 2

Estimation of the correction factor F for December, which accounts for the power transmission losses during the day operation of the PV system-loads, is given by the equation:

$$\frac{1}{P_m} \cdot \frac{dP_m}{dT_{pv}} \approx -0.45\% \left[\frac{1}{℃}\right] \qquad (3.41)$$

So, from eq. (3.41):

$$\frac{dP_m}{P_m} = -0.45\% \ \cdot \left(T_{pv} - 25℃\right) = -0.45\% \ \cdot (18.96℃ - 25℃) = \mathbf{2.7199}\%$$

The efficiency due to the temperature which developed on the surface of photovoltaics (Π_{temp}), is given by the equation:

$$\Pi_{temp} = \frac{100\% + dP_m/P_m\,\%}{100} \qquad (3.42)$$

So, from eq. (3.42):

$$\Pi_{temp} = \frac{100\% + 2.7199\%}{100} = \mathbf{1.027199}$$

The overall efficiency of the PV System (Π_i), is given by the equation:

$$\Pi_i = \Pi_{temp} \cdot \eta_{cables} \cdot \eta_{inverter} \cdot \eta_{pv-ageing} \quad (3.43)$$

So, from eq. (3.43):

$$\Pi_i = 1.027199 \cdot 0.98 \cdot 0.985 \cdot 0.90 = \mathbf{0.8924}$$

where the degradation of the efficiency of the PV System:

η_{cables}: due to losses in wiring. Assume a degradation of the efficiency by 2%.
$\eta_{inverter}$: losses due to the efficiency of the inverter. $\eta_{inverter}$=0.985 (see Table 3.2 → Technical Characteristics of the inverter).
$\eta_{pv\text{-}ageing}$: losses due to ageing of the photovoltaics. Assume a degradation of the efficiency by 10%. See Notes 1, 2 & 3.

- ✓ *Note 1: an average of 0.5%÷1% degradation per year is usually observed for PV modules. Assume the worst case of 1% degradation per year.*

- ✓ *Note 2: $\eta_{pv\text{-}ageing}$ is equal to 0.90, because the PV System is sized in order to be able to cover the loads after 10 years, despite the pv-ageing.*

- ✓ *Note 3: the PV System is sized to be able to cover the loads after 10 years, because most likely will not be applied the same power consumption after 10 years. E.g., the building will have been upgraded energy (new openings, insulation in walls, etc.), so the building will have less energy consumption. Also, in many cases, the apartments have periods not inhabited, so the building will have less energy consumption.*

The correction factor (F), is given by the equation:

$$F = \frac{1}{\Pi_i} \quad (3.44)$$

So, from eq. (3.44):

$$F = \frac{1}{0.8924} = \mathbf{1.12}$$

The same methodology will be followed in order to be calculated the correction factor F for all months for 20 years of operation of the PV System (see Tables 1a÷1d of Appendix III), as well as the PV System will be checked for possible operation of 20 years. Also, the mean annual correction factor, after 10 years of operation of the PV System, is equal to:

$\boldsymbol{F_m} = \mathbf{1.17}$ (see Table 1d of Appendix III)

Step 3

Estimation of the number of days of autonomy, is given by the equation:

$$d_{no-cr} = -0.48 \cdot (PSH)_{min} + 4.58 \; [days] \quad (3.45)$$

So, from eq. (3.45):

$$d_{no-cr} = -0.48 \cdot 1.04 + 4.58 = 4.0808 days$$

where:

PSH : peak solar hour (h/day)
PSH_{min} : minimum value of PSH (h/day)

- ✓ *Note 4: PSH is equal (numerically) to the daily solar radiation at horizontal (H→KWh). H is taken for the database SODA for 20 years (1985-2004). See Section 3.1.3.*

- ✓ *Note 5: in order to not be oversized the PV System, PSH_{min} is equal to the mean minimum value of H from the database SODA for 20 years (1985-2004).*

For December → PSH_m=1.49 (see Table 2a of Appendix III)
For December → PSH_{min}=1.04

Step 4

Finally, the peak power (P_m) is determined from the following equation:

$$P_m = \frac{d \cdot Q_L \cdot F}{PSH_m \cdot R_m} \tag{3.46}$$

So, from eq. (3.46):

$$P_m = \frac{4.0808 \cdot 98 \cdot 1.12}{1.49 \cdot 1.15879} = 259.4 KW_p$$

R_m is equal to the mean value of R from the database SODA for 20 years (1985-2004).

- For December → R_m=1.15879 (see Table 2b of Appendix III)
- For December → $Q_{L,DEC}$ = 98 KWh (see Table 3.1)
- For December → F_{DEC} = 1.12 KWh (see step 2 & Table 1d of Appendix III)*
  ** after 10 years of operation of the PV System*

- ✓ *Note 6: The purpose is not a Stand Alone PV-System, as the apartments are continuously connected to the grid and there is no risks of failure to coverage the loads. In this way, we achieve lower investment and maintenance costs of the PV System (no need of replacement of the batteries after the end of their life), as, there is no need to install batteries in the PV System, as it is continuously connected to the grid. So, assume a number of days of autonomy d_{no-cr} = 1.0.*

- ✓ *Note 7: As the PV System is not a Stand Alone PV System, we will use mean annual values for the parameters of Q_L, F, PSH & R.*

$$P_m = \frac{d_{no-cr} \cdot Q_{L,m} \cdot F_m}{PSH_m \cdot R_m} = \frac{1.0 \cdot 101 \cdot 1.17}{4.35 \cdot 1.08379} = \mathbf{25.065KW_p}$$

- Mean annual Electricity Consumption, $Q_L \rightarrow Q_{L,m}$=101 KWh (see Table 3.1)
- Mean annual Correction Factor, F → F_m: 1.17 (see Table 1d of Appendix III)*
  ** after 10 years of operation of the PV System*
- Mean annual value of R → R_m: 1.08379 (see Table 2b of Appendix III)

The final installed power of the PV generator is:

$\boldsymbol{P_m} = \mathbf{25.998KW_p}$ → **See step 11 (Confirmation)*

Step 5

In order to determine the daily solar radiation on the tilted surface of the PV panels (H_T) must be calculated the conversion factor R. In our case study, the PV System is located in Zakynthos with latitude φ=37.79° and longitude L=20.89°. The PV panels are placed to the horizontal with an angle β=25° to horizontal and with an azimuth angle γ=0°. The calculation of the conversion factor R will be done on December 1st. n, is the day of the year counted from the 1st of January. Therefore, on December 1st, n is equal to:

$$n = 31 + 29 + 31 + 30 + 31 + 30 + 31 + 31 + 30 + 31 + 30 + 1 = 336$$

The daily solar radiation on the horizontal (H) on December 1st, is equal to:

$$H = 1.48KWh$$

The values which are used for the daily solar radiation on the horizontal (H), are the mean values of H from the database SODA for twenty years (1985-2004).

The sun declination angle (δ) according to the equations (3.1) or (3.27), is equal to:

$$\delta = 23.45° \cdot sin\left(360 \cdot \frac{284 + 336}{365}\right) = -22.24°$$

The angle of the sunset or sunrise (ω_s) at horizontal according to the equations (3.12) or (3.28), is equal to:

$$\omega_s = cos^{-1}[-tan37.79° \cdot tan(-22.24°)] = 71.52°$$

The sunset hour angle (ω_s') for the inclined surface (β=25°) of the PV panels according to the equations (3.13) or (3.35), is equal to:

$$\omega_s' = min[\omega_s, cos^{-1}[-(tan(37.79° - 25°)) \cdot tan(-22.24°)]] =>$$

$$\omega_s' = min[71.52°, 84.67°] = 71.52^{\circ}$$

The daily extraterrestrial solar radiation on the horizontal surface (H_{ext}) according to the equations (3.19) or (3.30), is equal to:

$$H_{ext}(336) = \frac{24 \cdot 3600}{\pi} \cdot 1353 \cdot \left[1 + 0.033 \cdot cos\left(\frac{360 \cdot 336}{365}\right)\right]$$

$$\cdot \left[cos(37.79°) \cdot cos(-22.24°) \cdot sin(71.52°) + \frac{\pi \cdot 71.52°}{180} \cdot sin(37.79°) \cdot sin(-22.24°)\right]$$
$$\div 36 \cdot 10^5 \rightarrow$$

$$H_{ext}(336) = 4.30KWh$$

The clearness index (K_T) according to the equation (3.26), is equal to:

$$K_T = \frac{1.48KWh}{4.30KWh} = 0.34$$

The Hd/H ratio i.e. the diffuse daily solar radiation over the total (global) one, according to the equation (3.29), is equal to:

$$K_T = 0.34 \rightarrow if\ 0.17 < K_T < 0.75\ then \rightarrow$$

$$\frac{H_d}{H} = 1.188 - 2.272 \cdot K_T + 9.473 \cdot K_T^2 - 21.865 \cdot K_T^3 + 14.648 \cdot K_T^4 \rightarrow$$

$$\frac{H_d}{H} = 1.188 - 2.272 \cdot 0.34 + 9.473 \cdot 0.34^2 - 21.865 \cdot 0.34^3 + 14.648 \cdot 0.34^4 \rightarrow$$

$$\frac{H_d}{H} = 0.84$$

The daily conversion coefficient of the beam solar insolation from the horizontal to the inclined plane (R_b) according to the equations (3.25) or (3.34), is equal to:

$$R_b = \frac{cos(\varphi - \beta) \cdot cos(\delta) \cdot sin(\omega_s') + (\pi/180) \cdot \omega_s' \cdot sin(\varphi - \beta) \cdot sin(\delta)}{cos(\varphi) \cdot cos(\delta) \cdot sin(\omega_s) + (\pi/180) \cdot \omega_s \cdot sin(\delta) \cdot sin(\varphi)} = 1.86$$

wherein:

$$\varphi = 37.79°$$
$$\beta = 25°$$
$$\delta = -22.24$$
$$\omega_s = \omega_s' = 71.52°$$

The conversion factor R according to the equation (3.36), is equal to:

$$R = (1 - 0.84) \cdot 1.86 + 0.84 \cdot \left(\frac{1 + cos\,25}{2}\right) = \ 1.13229$$

wherein:

r=0, because the backside of photovoltaics is not exploited for electricity generation.

Step 6

Estimation of E_{PV}, DE, $E_{PV,Real}$, $E_{PV,Real}/E_{PV}$ & DE/Q_L (after 10 years of operation of the PV System).

wherein:

E_{PV} : The energy produced by the PV System with the same peak power P_m in a day, KWh/day,
DE : the remaining amount of energy delivered by the PV System, after its consumption by the load, KWh/day,
$E_{PV,Real}$: the real energy delivered by the PV System after its degradation, KWh/day,
$E_{PV,Real}/E_{PV}$: the percentage of the real energy delivered by the PV System after its degradation, as to the maximum energy that could be delivered by the PV System, %,
DE/Q_L : the percentage of the excess or lack of electrical energy in relation to the electricity needs of the apartments, %.

also:

$P_m = 25.998 KW_p$ (see step 4)
$PSH = H = 1.48 \rightarrow$ for December 1^{st} (see step 3)
$R = 1.13229 \rightarrow$ for December 1^{st} (see step 5)
$F = 1.12$ (see step 2 & $Table\ 1d$ of Appendix III)
$Q_L = 98\, KWh/day \rightarrow$ for December 1^{st} (see Table 3.1)

The energy produced by a PV System with the same peak power P_m in a day according to the equation (3.39), is equal to:

$$E_{PV} = P_m \cdot PSH \cdot R = 25.998 \cdot 1.48 \cdot 1.13229 = 43.57KWh$$

Also, expressed in money:

$$E_{PV} = 43.57KWh \cdot 0.23\,€/KWh = 10.02€$$

The remaining amount of energy delivered by the PV System, after its consumption by the load, is determined from the following equation:

$$DE = E_{PV} - F \cdot Q_L \qquad [KWh/day] \qquad (3.47)$$

So, from eq. (3.47):

$$DE = E_{PV} - F_{[Dec]} \cdot Q_{L[Dec]} = 43.57 - (1.12 \cdot 98) = -66.19KWh$$

Also, expressed in money:

$$DE = -66.19KWh \cdot 0.23\,€/KWh = -15.22€$$

The real energy delivered by the PV System after its degradation, is determined from the following equation:

$$E_{PV,Real} = Q_L + DE \qquad [KWh/day] \tag{3.48}$$

So, from eq. (3.48):

$$E_{PV,Real} = Q_{L[Dec]} + DE = 98 + (-66.19) = 31.81KWh$$

Also, expressed in money:

$$E_{PV,Real} = 31.81KWh \cdot 0.23\,€/KWh = 7.32€$$

The percentage of the real energy delivered by the PV System after its degradation, as to the maximum energy that could be delivered by the PV System, is determined from the following equation:

$$E_{PV,Real}/E_{PV} \qquad [\%] \tag{3.49}$$

So, from eq. (3.49):

$$E_{PV,Real}/E_{PV} = 31.81/43.57 = 0.730 = 73.0\%$$

The percentage of degradation of the excess or lack of electrical energy in relation to the daily electricity needs of the apartments, is determined from the following equation:

$$DE/Q_L \qquad [\%] \tag{3.50}$$

So, from eq. (3.50):

$$DE/Q_{L[Dec]} = -66.19/98 = -0.675 = -67.5\%$$

- ✓ *Note 8: R is calculated by mean values of R from the database SODA for 20 years (1985-2004).*

- ✓ *Note 9: All of the energy produced by the PV System will be given to PPC for its immediate utilization. Until now the energy for the coverage of the loads was being purchased by a private company which has selling price of electricity power 0.23€/KWh. After installation of the PV System, the energy for the coverage of the electrical loads will be done through PPC. At the end of each year, will be done offsetting of the energy generated by the PV System with the energy needs of the hotel complex, according to the program "Net Metering".*

✓ *Note 10: If DE has a positive sign, then we have Excess of Energy. This Excess of Energy is sold to a neighboring company to cover a small part of its energy needs at sale price of 0.23€/KWh. On the other hand, if DE has a negative sign, then we have Lack of Energy. I.e., at that time period the undertaking will have to buy electricity from PPC.*

The same methodology is followed in order to be calculated the parameters E_{PV}, DE, $E_{PV,Real}$, $E_{PV,Real}/E_{PV}$ and DE/Q_L for all days of the year. The values were used for the daily solar radiation at horizontal (H or PSH), are the mean values of H from the database SODA for twenty years (1985-2004). In Appendix III are shown the results of the parameters Q_L, E_{PV}, DE, $E_{PV,Real}$, $E_{PV,Real}/E_{PV}$ and DE/Q_L in these forms:

- Simulation for the parameters Q_L, E_{pv}, $E_{PV,Real}$ and DE for three years indicatively (1st, 10th & 20th year), for all days of all months (see Graph 1 of Appendix III) → [KWh/day].
- Mean monthly values for the parameters Q_L, E_{pv}, $E_{PV,Real}$ and DE for 20 years of operation of the PV System → [KWh/year].
  i. considering all the months together (see Graph 2 of Appendix III).
  ii. considering each month separately (see Graph 3 of Appendix III).
- Annual average values for the parameters Q_L, E_{pv}, $E_{PV,Real}$ and DE for 20 years of operation of the PV System (see Graphs 4a & 4b of Appendix III) → [KWh/year] & [€/year].
- Presentation of the mean monthly values of the parameters I_{hourly}, $I_{T,hourly}$, T_a, T_{PV}, DP_m/P_m, Π_{temp}, Π_i, F, $I_{monthly}$, Q_L, E_{PV}, DE, $E_{PV,Real}$, $E_{PV,Real}$/ E_{PV} & $DE/Q_{L,}$ and the interaction between them – average values of the 20 years of operation of the PV System (see Graphs 5a÷s of Appendix III).
- Presentation of the annual average values, for the 20 years of operation of the PV System, of the parameters $\eta_{pv\text{-}ageing}$, Π_i, F, Q_L, E_{PV}, DE, $E_{PV,Real}$, $E_{PV,Real}$/ E_{PV} & DE/Q_L and the interaction between them (see Graphs 6a÷m of Appendix III).
- Detailed calculation of Correction Factor F for all months for 20 years of operation of the PV System - mean monthly values (see Tables 1a÷d of Appendix III).
- PivotTables of the parameters of I, R, Q_L, E_{PV}, DE, $E_{PV,Real}$ and the ratios of $E_{PV,Real}/E_{PV}$, DE/Q_L - mean monthly values (see Tables 2a÷l of Appendix III).

Step 7: Types of PV–panels to be installed

Decide on the PV–panels to be installed. The type of the PV–panels was selected is *aleo S18* with the following characteristics:

I_{sc} = 9.14A, V_{oc} = 37.7V, I_m = 8.64A, V_m = 30.7 V, $P_m = I_m \cdot V_m$= 265.248 ≈ **265W$_p$**

Step 8: Correct P_m, V_m, I_m due to field conditions; mainly due to PV temperature T_c

The operating temperature T_{pv} of the PV panels according to the equation (3.40), is equal to:

$$T_{pv} = T_a + \lambda \cdot I_T$$

T_a: is the mean daily ambient temperature
λ = 0.01 (for strong wind conditions) ÷ 0.035 (for mild wind conditions)

The mean daily ambient temperature (T_a) in Zakynthos will be considered for the warmest month of the year, who is July, in order to make clear the correction process to the electrical characteristics of the PV panels. The mean daily ambient temperature is taken from the database PVGIS and is equal to 26.2 °C for July.

"I" is the maximum value of the hourly solar radiation at horizontal where observed from the hourly data of two years (2004 & 2005) from the database SODA for the month of July (warmest month). The maximum values were observed at 1-7-2005 at 12:00 (solar noon) & 13:00, and is equal to 948 W/m^2 & 949 W/m^2 for the month of July.

For β = 25° and γ = 0°:

$$At\ 12{:}00 \rightarrow I_T = 953\, W/m^2$$

$$At\ 13{:}00 \rightarrow I_T = 952\, W/m^2$$

hence:

$$T_{pv} = 26.2℃ + 0.03 \cdot 953\, W/m^2 = \mathbf{54.79}℃$$

The values of I_{sc}, V_{oc}, FF are corrected for this PV temperature. The temperature effect on I_{sc} is negligible. Hence:

$$I_{sc} = 9.14A$$

The corrected V_{oc} due to temperature for the PV panel of 36 cells is:

$$V_{oc,cor} = V_{oc} - 36 \cdot 0.0023\, V/℃ \cdot \left(T_{pv} - 25\right)℃ \tag{3.51}$$

So, from eq. (3.51):

$$V_{oc,cor} = 37.7V - 36 \cdot 0.0023\, V/℃ \cdot (54.79 - 25)℃ = \mathbf{35.23V}$$

For the calculation of V_{oc}, it is used the equation of Fill Factor (FF):

$$FF = \frac{P_m}{I_{sc} \cdot V_{oc}} \tag{3.52}$$

So, from eq. (3.52):

$$FF = \frac{265W_p}{9.14A \cdot 37.7V} = \mathbf{0.769}$$

It is assumed that FF does not change substantially with T_{pv}. Finally, P_m is determined for conditions I_T = 1000W/m^2 and T_{pv}=54.79°C according to the equation (3.52):

$$P_{m,cor} = I_{sc} \cdot V_{oc,cor} \cdot FF = 9.14A \cdot 35.23V \cdot 0.769 = \mathbf{247.6W}$$

Instead of the 265 W_p at STC conditions. The corrected P_m due to temperature is to be used for the correction in the sizing.

Step 9: Determine the number of PV-panels, N_{pv}

The number of PV panels is estimated by:

$$N_{pv} = \frac{P_{m,generator}}{P_{m,cor}} \tag{3.53}$$

So, from eq. (3.53):

$$N_{pv} = \frac{25065W_p}{247.6W_p} = 101.23 \rightarrow N_{pv} = \mathbf{102}\ PV\ panels$$

Step 10: Decide on the DC voltage V for the power transfer

The decision affects the PV System elements and PV panels electrical connections, as cable losses depend on the size or cross-section of the cables and the DC voltage.

Consider the case of V=1000V (see Table 3.2 → Maximum input voltage of the inverter). Taking a safety factor 5%, the DC voltage for the power transfer is equal to 95% · 1000V = 950V. Then, the number of panels in series is estimated by:

$$N_{p,s} = \frac{V}{V_m} \tag{3.54}$$

So, from eq. (3.54):

$$N_{p,s} = \frac{950V}{30.7V} = 30.94 \rightarrow N_{p,s} \approx \mathbf{30}\ PV\ panels\ in\ series$$

Therefore, the number of strings of PV panels in parallel is estimated by:

$$N_{p,p} = N_{pv}/N_{p,s} \tag{3.55}$$

So, from eq. (3.55):

$$N_{p,p} = 102/30 = 3.4 \rightarrow N_{p,p} \approx \mathbf{4}$$

The PV generator has 4 strings of PV panels in parallel and each string has 30 panels in series. Total number of PV panels is 120.

✓ *Note 11: In this calculation the V_m value is given by the specifications and is not corrected due to temperature. The corrected value of V_m is determined by:*

$$V_{m,cor} = \frac{P_{m,cor}}{I_m} \tag{3.56}$$

where $P_{m,cor}$ is the corrected peak power of the PV panel and I_m is taken from specifications as it is not essentially affected by the temperature. Hence:

$$V_{m,cor} = \frac{247.6W_p}{8.64A} = \mathbf{28.66V}$$

which gives:

$$N_{p,s} = \frac{V}{V_{m,cor}} = \frac{950V}{28.66V} = 33.15 \rightarrow N_{p,s} = \mathbf{33}\ PV\ panels\ in\ series$$

In order to not be oversized the PV System we select:

$$N_{p,s} = 26\ PV\ panels\ in\ series$$

Therefore, the number of strings of PV panels in parallel is:

$$N_{p,p} = 102/26 = 3.92 \rightarrow N_{p,p} \approx \mathbf{4}$$

The PV generator has 4 strings of PV panels in parallel and each string has 26 panels in series. The total number of the PV panels is 104.

Finally, at the request of the client, the PV generator has 4 strings of PV panels in parallel. The three strings have 26 panels in series and the other one 27 panels in series. The total number of the PV panels is **105**.

In fact, the problem is transferred to the choice of the type and the configuration of the DC/AC inverters, which may be of multi - string type and where the I-V MPP region must lie in the middle of the operational margin of the inverter.

Step 11: Confirmation

In Step 9 N_{pv} was estimated equal to 102 PV–panels. Hence:

$$P_m = 102 \cdot 247.6W_p = \mathbf{25255.2W_p} > 25065W_p$$

Which is just above to the P_m=25065W_p calculated in Step 4. However, the result of the pv-sizing was 105 PV panels, which is:

$$P_m = 105 \cdot 247.6W_p = \mathbf{25998W_p} > 25065W_p$$

This value exceeds the load of 25065W, by a safety factor:

$$SF = \frac{25998 - 25065}{25065} \cdot 100 = \mathbf{3.72}\%$$

3.3 INVERTER'S OPERATIONAL MARGIN

When investigating the proper DC/AC inverter, the same concept of safe operation area (SOAR) also applies here. The MPP point of the PV generator needs to always fall well within the operational margin region of the inverter (Kaplanis and Kaplani, 2013).

In our case study, two inverters *"Sunny Tripower 15000TL High Efficiency*" will be used with the following Technical Characteristics. Two strings will be connected to the one inverter and two strings will be connected to the other inverter.

Table 3.3: Technical characteristics of the inverter: «Sunny Tripower 15000TL High Efficiency» (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf)

DC input

Maximum power DC with cos φ = 1	15200 W
Maximum input voltage *	1000 W
Range of voltage MPP at 230 V AC	580 V to 800 V
Rated input voltage	580 V
Minimum input voltage at 230 V AC	570 V
Initial input voltage	620 V
Maximum input current	36 A
Maximum input current per string	36 A
Number of independent maximum power point inputs (MPP)	1
Strings per input MPP	6

** The maximum open circuit voltage, which can occur at a cell temperature of -10°C, may not exceed the maximum input voltage.*

AC Output

Rated power at 230 V, 50 Hz	15000 W
Maximum apparent power AC	15000 VA
Rated grid voltage	3/N/PE, 230 V / 400 V
Range of voltage AC	160 V to 280 V
Rated current AC at 230 V	21,7 A
Maximum output current	24,0 A
Maximum short-circuit current	50 A
Rated grid frequency	50 Hz
Distortion factor of output current for distortion factor of voltage AC < 2%, power AC > 0,5 rated power	≤ 2,6%
Maximum output failure current	96 mA
Grid frequency AC*	50 Hz to 60 Hz
Operating range at mains frequency AC 50 Hz	44 Hz to 55 Hz
Operating range at mains frequency AC 60 Hz	54 Hz to 65 Hz
Displacement power factor, adjustable	$0{,}8_{\text{with overstimulation}}$ to $0{,}8_{\text{with understimulation}}$
Power phases	3
Connection phases	3
Overvoltage category	III

** Depending on the country setting*

Efficiency

Maximum efficiency, n_{max}	99%
European efficiency,, n_{EU}	98,5%

For the design in our Case Study, 2 such strings were connected in parallel at each inverter, with (see Figure 3.13):

- 1st string (26 panels in series are connected to input A1 – Inverter No.1):
  $V_m = N_{p,s} \cdot V_{m,cor} = 26 \cdot 28.66V = 745.16V < 1000V$
  $I_m = 1\,string \cdot I_m = 1 \cdot 8.64A = 8.64A < 36A$

- 2nd string (26 panels in series are connected to input A2 – Inverter No.1)
  $V_m = N_{p,s} \cdot V_{m,cor} = 26 \cdot 28.66V = 745.16V < 1000V$
  $I_m = 1\,string \cdot I_m = 1 \cdot 8.64A = 8.64A < 36A$

- 3rd string (26 panels in series are connected to input A1 – Inverter No.2)
  $V_m = N_{p,s} \cdot V_{m,cor} = 26 \cdot 28.66V = 745.16V < 1000V$
  $I_m = 1\,string \cdot I_m = 1 \cdot 8.64A = 8.64A < 36A$

- 4th string (27 panels in series are connected to input B1 – Inverter No.2)
  $V_m = N_{p,s} \cdot V_{m,cor} = 27 \cdot 28.66V = 773.82V < 1000V$
  $I_m = 1\,string \cdot I_m = 1 \cdot 8.64A = 8.64A < 36A$

The DC/AC inverter must be of 580V DC rated input voltage, with an operating margin from 580V to 800V and maximum input current 36A which is a common specification (see Table 3.3). This unit would operate safely.

The principle of operation of the PV System with the inverter is shown in the figure below:

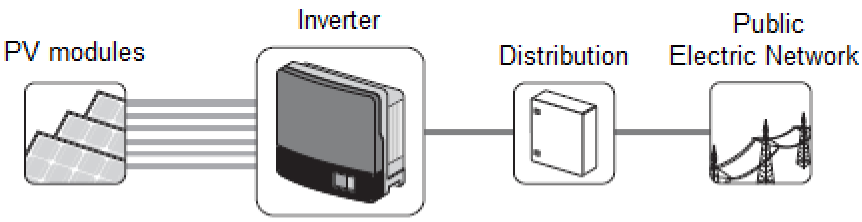


Figure 3.9: The principle of operation of the PV system with the inverter (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf)

3.3.1 Reverse current protection

Every input area of the inverter is equipped with a diode as reverse current protection. A reverse current between the input areas is therefore not possible.

If only input area A is used and the reverse current resistance of the PV modules is complied with, the reverse current protection at input area A can be bypassed. Bypassing the reverse current protection slightly increases the inverter efficiency. The reverse current protection at input area B cannot be deactivated (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf).

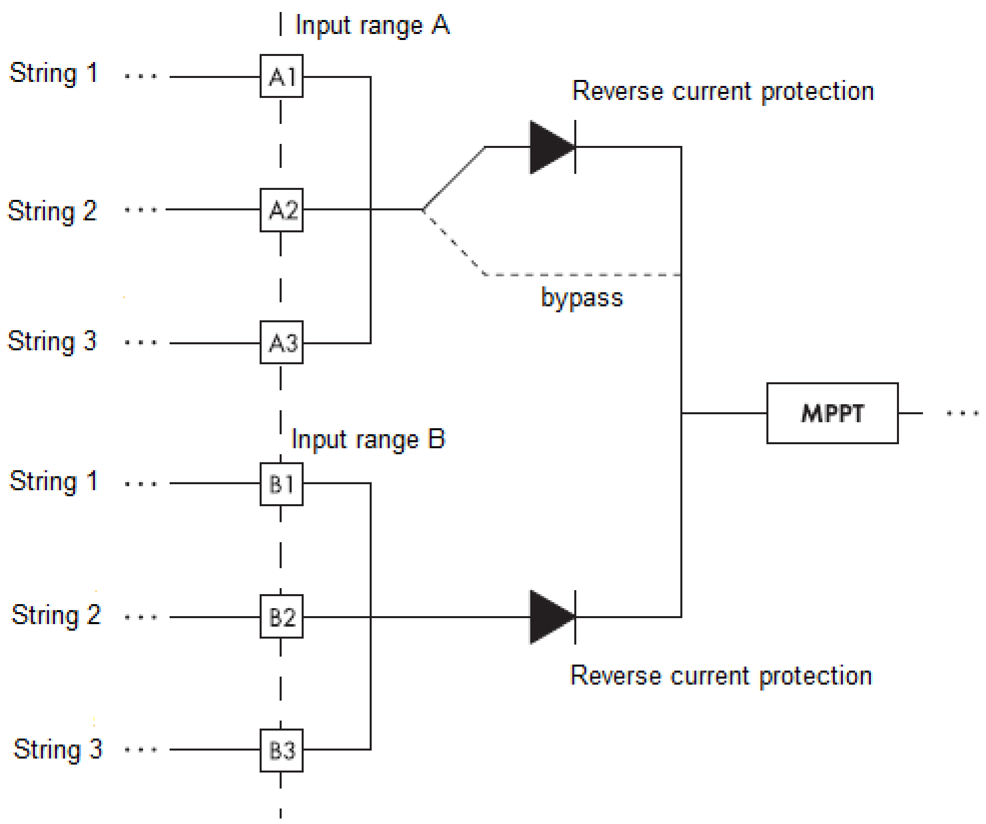


Figure 3.10: Reverse current protection (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf)

The overview of the connection area is shown in the figures below:

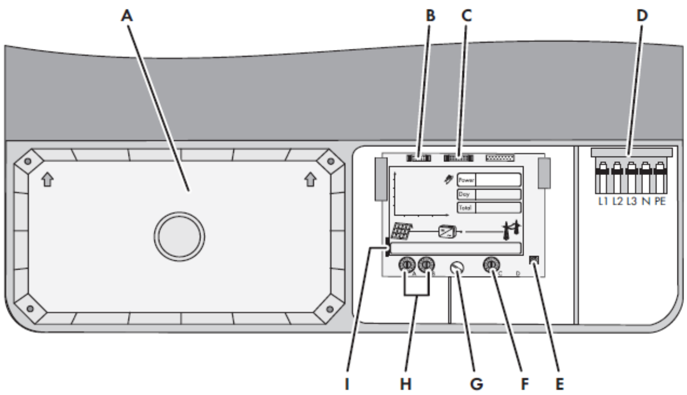


Figure 3.11: Overview of the connection area (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf)

Table 3.4: Description of Figure 3.11 (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf)

Object	Description
A	DC lid
B	Plug for connecting the optional multi-function relay
C	Plug for connecting the optional RS485 communication module
D	Terminal for grid connection
E	Switch for changing the display language to English (for service purposes)
F	Rotary switch for setting the Bluetooth NetID
G	Screw for releasing and raising the display
H	Rotary switch for setting the country data set and display language
I	Slot for SD card (for service purposes only)

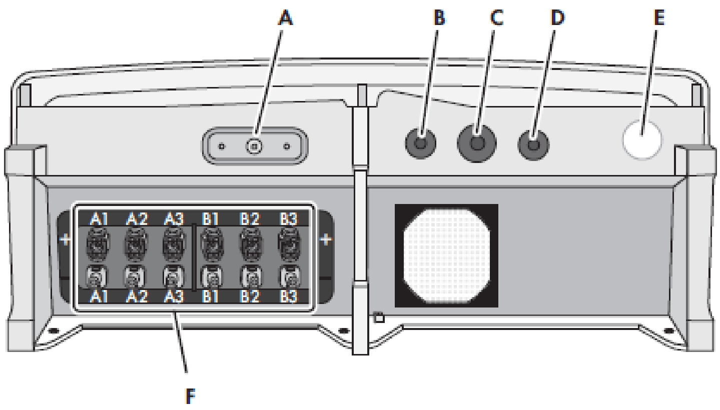


Figure 3.12: Overview of the connection area (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf)

Table 3.4: Description of Figure 3.12 (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf)

Object	Description
A	Jack for the handle of the DC switch-disconnector*
B	Enclosure opening M20 for the optional multi-function relay
C	Enclosure opening M32 for optional communication via RS485
D	Additional enclosure opening M20
E	Enclosure opening M32 for the AC connection
F	DC connectors for connecting the strings

**optional*

3.3.2 Conditions for DC Connection

The inverter has 2 input areas, "A" and "B", each with its own reverse current protection. In total, up to 6 strings can be connected.

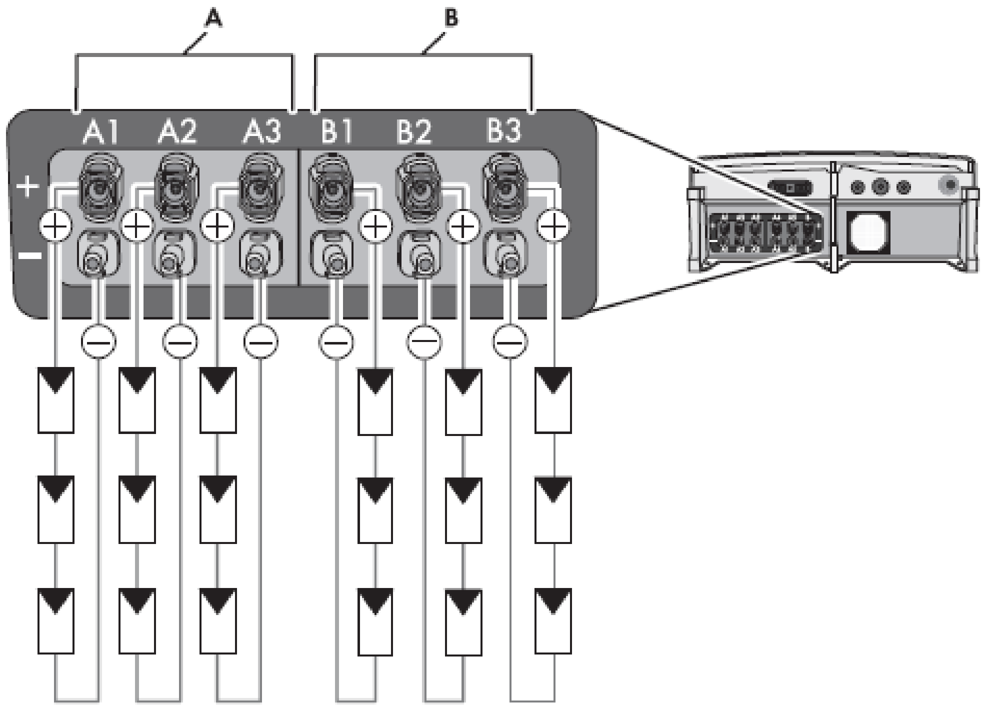


Figure 3.13: Connection of strings at any input (http://files.sma.de/dl/20929/STP20TLHE-IA-IEN122222.pdf)

Requirements for the PV modules of the connected strings:

a. Same type
b. Same quantity of PV modules connected in series
c. Identical alignment
d. Identical tilt

3.4 POWER LOSSES IN CABLES

The DC power transfer voltage is 745.16V (1st, 2nd & 3rd string – worst case) and 773.82V (4th string). The overall cable length from the PV array to the DC/AC inverter should be the shortest possible. However, with an increase in the DC transfer voltage V the cable cross-section may be reduced and, therefore reduce the capital cost. For this it is useful to have tabulated values of the wire resistance per unit length R_{cable} (Ohm/m) for various cross-section areas (CSA), as provided in Table 3.5 (Kaplanis and Kaplani, 2013).

Table 3.5: Wire resistance vs cross-section (Kaplanis S. and Kaplani E., 2013)

Conductor cross-section area (mm^2)	Resistance Ohms/m
2.5	0.0074
4	0.0046
6	0.0031
10	0.0018
16	0.0012
25	0.00073

The voltage drop δv from the value of V is calculated by the following expression.

$$\delta v = I_{PV} \cdot R_{cable} \cdot 2L \qquad (3.57)$$

where, the cable length is doubled for obvious reasons.

In our case study the cross-section of cables is $6mm^2$ and the cable length (L) is 10m.

$I_{PV} = 1string \cdot I_m = 1 \cdot 8.64 = 8.64A$ (see Figure 3.13)

For cross-section $6mm^2$:

$$\delta v = 8.64A \cdot 0.0031\,\Omega/m \cdot 2 \cdot 10m = 0.53568V$$

$$cable\ losses = (0.53568V/745.16V) \cdot 100 = 0.07\% < 2\%$$

The cable losses must be lower than 2%. Also, as the cross-section increases the voltage drop decreases.

3.5 CONCLUSIONS

- 1st conclusion:

In Table 2k of Appendix III, is shown the percentage of the real energy delivered by the PV System after its degradation, $E_{PV,Real}$ (losses due to high temperatures being developed → Π_{temp}, losses in wiring → η_{cables}, losses due to the efficiency of the inverter → $\eta_{inverter}$ and finally losses due to ageing of the photovoltaics → $\eta_{pv\text{-}ageing}$) as to the maximum energy that could be delivered by the PV System, E_{PV} (i.e. without the abovementioned losses) per month for 20 years. I.e. is shown the ratio $E_{PV,Real}/E_{PV}$. All losses are considered to be stable over time, except losses due to ageing of the photovoltaics, where considered that there is a degradation of their performance 1% annually.

Observing the Table 2k of Appendix III, is observed that there is a reduction in the percentage of the ratio $E_{PV,Real}/E_{PV}$ for each year of operation of the PV System and for all months. To explain the reasons this happens (as well as other questions that will arise below) we will remember some equations that were used for the sizing of the PV System (see Section 3.2). So we have:

$$T_{pv} = T_a + \lambda \cdot I_T \qquad [℃] \tag{3.58}$$

$$\frac{1}{P_m} \cdot \frac{dP_m}{dT_{pv}} \approx -0.45\% \left[\frac{1}{℃}\right] \rightarrow \frac{dP_m}{P_m} = -0.45\% \cdot \left(T_{pv} - 25℃\right) \qquad [\%] \tag{3.59}$$

$$\Pi_{temp} = \frac{100\% + \frac{dP_m}{P_m}\%}{100} \tag{3.60}$$

$$\Pi_i = \Pi_{temp} \cdot \eta_{cables} \cdot \eta_{inverter} \cdot \eta_{pv-ageing} \tag{3.61}$$

$$F = \frac{1}{\Pi_i} \tag{3.62}$$

$$E_{PV} = P_m \cdot PSH \cdot R \qquad [KWh/month] \tag{3.63}$$

$$DE = E_{PV} - F \cdot Q_L \qquad [KWh/month] \tag{3.64}$$

$$E_{PV,Real} = Q_L + DE \qquad [KWh/month] \tag{3.65}$$

$$E_{PV,Real}/E_{PV} \qquad [\%] \tag{3.66}$$

$$DE/Q_L \qquad [\%] \tag{3.67}$$

Knowing that photovoltaics have a degradation in their performance 1% annually due to ageing ($\eta_{pv\text{-}ageing}$), we observe that the overall efficiency of the PV System (Π_i) decreases annually for all months. Consequently, the correction factor (F) increases annually for all months and therefore the remaining amount of energy delivered by the PV System after its consumption by the load (DE) and the real energy delivered by the PV System after its degradation ($E_{PV,Real}$) decrease annually for all months. Finally, the ratio $E_{PV,Real}/E_{PV}$ decreases annually for all months. See the above equations 3.61, 3.62, 3.64 & 3.65 and the following logic diagram:

[↑]: when increases

[↓]: when decreases

$$\eta_{pv-ageing}[\downarrow] \rightarrow \Pi_i[\downarrow] \rightarrow F[\uparrow] \rightarrow DE[\downarrow] \rightarrow E_{PV,Real}[\downarrow] \rightarrow \frac{E_{PV,Real}}{E_{PV}}[\downarrow]$$

To better understand how these parameters operate and what interaction they have between them, see the annual average values in 20 years of operation of the PV System in Tables 1b, 1c, 1d, 2e, 2i, 2k & Graphs 6a, 6b, 6c, 6f, 6j, 6l of Appendix III.

Observing the Table 2k of Appendix III (the annual degradation of the PV System - the last row of Table), we notice that the ratio $E_{PV,Real}/E_{PV}$ has a reduction of 0.9%÷1.6% annually. Also, in the same Table, we observe that at the end of 1st year of operation of the PV System, its annual degradation is 5.8%. This is due to the remaining losses of the PV System (Π_{temp}, η_{cables} & $\eta_{inverter}$) which are considered to be stable over time. So, the only further reduction of the performance of the PV System after the 1st year of its operation is due to losses due to ageing of the photovoltaics.

We reach the same conclusion observing in Table 2l of Appendix III the monthly and annual values of the ratio DE/Q_L as well as the last row of the same Table which shows the percentage of degradation of the excess or lack of electrical energy in relation to the annual electricity needs of the apartments.

The purchase and sale price of electricity is 0.23 €/KWh. Observing the Table 2l of Appendix III the penultimate and last line and Graph 6m of Appendix III the annual values of the ratio DE/Q_L as well as the rate of degradation of the excess or lack of the electrical energy and the Tables 2e, 2i & Graphs 6f, 6j of Appendix III the annual values of DE (KWh & €) we notice the following:

i. At the 1st year of operation of the PV System, it gives excess of energy of 10.2% (DE = 3773 KWh → 868 €).
ii. At the 2nd year of operation of the PV System there is a degradation of excess of energy of 1.2%. So, the PV System gives excess of energy of 9.0% (DE = 3332 KWh → 766 €), etc.
iii. At the 10th year of operation of the PV System, it gives lack of energy of -0.5% (DE = -171 KWh → -39 €).
iv. At the end of the 20th year of operation of the PV System, it gives lack of energy of -15.1% (DE = -5573 KWh → -1282€).
v. Overall in 20 years of operation of the PV System, which is the minimum value of useful operating time of PV System, it gives lack of energy just -1,5% (DE = -11322 KWh → -2604 €).

2st conclusion:

Observing the Table 2k & Graph 5r of Appendix III and the relationships 3.58÷3.65 we notice that the ratio $E_{PV,Real}/E_{PV}$ alter according to the correction factor (F), the electrical load that must be covered by the PV System (Q_L) and the maximum possible energy produced by the PV System with the same peak power P_m (E_{PV}). Each parameter separately affects the ratio $E_{PV,Real}/E_{PV}$ as follows.

1. During the summer months due to the high solar radiation (I & I_T) and the high external temperatures (T_a) that prevail, the temperature which developed on the surface of photovoltaics increases (T_{PV}), and therefore the power transmission losses during the day operation of the PV system-loads (dP_m/P_m) decreases, the efficiency due to the temperature which developed on the surface of photovoltaics (Π_{temp}) decreases, the correction factor (F) increases, the remaining amount of energy delivered by the PV System after its consumption by the load (DE) decreases, the real energy produced by the PV System with the same peak power P_m ($E_{PV,Real}$) decreases and finally the ratio $E_{PV,Real}/E_{PV}$ decreases. Exactly the opposite occurs in the winter months. See the above equations 3.58÷3.65 and the following logic diagrams.

During the summer months:

$$I_T[\uparrow]\ \&\ T_a[\uparrow] \rightarrow T_{pv}[\uparrow] \rightarrow \frac{dP_m}{P_m}[\downarrow] \rightarrow \Pi_{temp}[\downarrow] \rightarrow \Pi_i[\downarrow] \rightarrow F[\uparrow]$$

$$\rightarrow DE[\downarrow] \rightarrow E_{PV,Real}[\downarrow] \rightarrow \frac{E_{PV,Real}}{E_{PV}}[\downarrow]$$

Conversely, during the winter months:

$$I_T[\downarrow]\ \&\ T_a[\downarrow] \rightarrow T_{pv}[\downarrow] \rightarrow \frac{dP_m}{P_m}[\uparrow] \rightarrow \Pi_{temp}[\uparrow] \rightarrow \Pi_i[\uparrow] \rightarrow F[\downarrow]$$

$$\rightarrow DE[\uparrow] \rightarrow E_{PV,Real}[\uparrow] \rightarrow \frac{E_{PV,Real}}{E_{PV}}[\uparrow]$$

To better understand how these parameters operate and what interaction they have between them, see the annual average values in 20 years of operation of the PV System in Tables 1a, 1c, 1d & 2a÷2k and Graphs 5a÷5r of Appendix III.

2. Observing the equations 3.64 & 3.65, we notice that when the electrical loads increase, which must be covered by the PV System (Q_L), increases the product ($F \cdot Q_L$). Consequently, the remaining amount of energy delivered by the PV System after its consumption by the load (DE) decreases, the real energy delivered by the PV System after its degradation ($E_{PV,Real}$) decreases and finally the ratio $E_{PV,Real}/E_{PV}$ decreases. Exactly the opposite occurs when decrease the electrical loads. See the following logic diagrams:

If:

$$Q_L[\uparrow] \rightarrow (F \cdot Q_L)[\uparrow] \rightarrow DE[\downarrow] \rightarrow E_{PV,Real}[\downarrow] \rightarrow \frac{E_{PV,Real}}{E_{PV}}[\downarrow]$$

Conversely if:

$$Q_L[\downarrow] \rightarrow (F \cdot Q_L)[\downarrow] \rightarrow DE[\uparrow] \rightarrow E_{PV,Real}[\uparrow] \rightarrow \frac{E_{PV,Real}}{E_{PV}}[\uparrow]$$

To better understand how these parameters operate and what interaction they have between them, see the annual average values in 20 years of operation of the PV System in Tables 2c, 2e, 2f, 2g, 2i, 2j, 2k & Graphs 5j, 5l, 5m, 5n, 5p, 5q, 5r of Appendix III.

3. Observing the equations 3.63, 3.64 & 3.65 we notice that during the summer months due to the high solar radiation (I), the maximum possible energy produced by the PV System with the same peak power P_m (E_{PV}) increases. Consequently, the remaining amount of energy delivered by the PV System after its consumption by the load (DE) increases, the real energy delivered by the PV System after its degradation ($E_{PV,Real}$) increases and finally the ratio $E_{PV,Real}/E_{PV}$ increases. Exactly the opposite occurs in the winter months. See the following logic diagrams.

During the summer months:

$$I[\uparrow] \rightarrow E_{PV}[\uparrow] \rightarrow DE[\uparrow] \rightarrow E_{PV,Real}[\uparrow] \rightarrow \frac{E_{PV,Real}}{E_{PV}}[\uparrow]$$

Conversely, during the winter months:

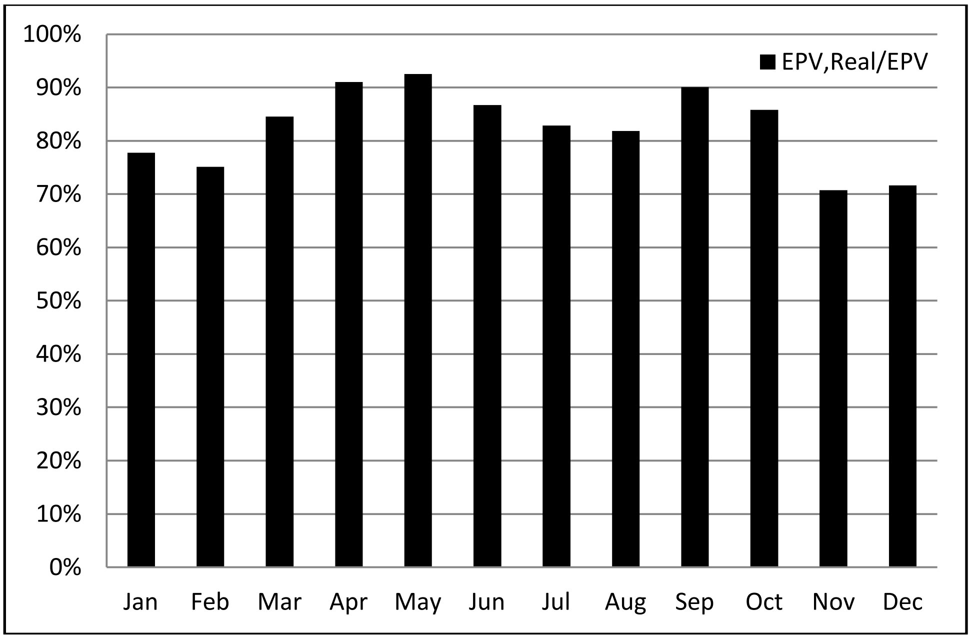
$$I[\downarrow] \rightarrow E_{PV}[\downarrow] \rightarrow DE[\downarrow] \rightarrow E_{PV,Real}[\downarrow] \rightarrow \frac{E_{PV,Real}}{E_{PV}}[\downarrow]$$

To better understand how these parameters operate and what interaction they have between them, see the annual average values in 20 years of operation of the PV System in Tables 2a, 2d, 2e, 2f, 2h, 2i, 2j, 2k & Graphs 5i, 5k, 5l, 5m, 5o, 5p, 5q, 5r of Appendix III.

In the following Table 3.6, using the monthly average values in 20 years of operation of the PV System for the parameters F, Q_L & E_{PV} (see Tables 1d, 2c & 2d of Appendix III), are calculated the annual average values in 20 years of operation of the PV System for the parameters DE, $E_{PV,Real}$ and $E_{PV,Real}/E_{PV}$. In the following Graph 3.1 is shown how the ratio $E_{PV,Real}/E_{PV}$ is affected by the parameters F, Q_L & E_{PV}.

Table 3.6: The annual average values in 20 years of operation of the PV module for the parameters F, Q_L, E_{PV}, DE, $E_{PV,Real}$ & $E_{PV,Real}$/ E_{PV}

Month	F	Q_L [KWh]	E_{PV} [KWh]	DE [KWh]	$E_{PV,Real}$ [KWh]	$E_{PV,Real}/E_{PV}$
Jan	1,13	3130	1791	-1737	1393	77,8%
Feb	1,14	4150	2327	-2402	1748	75,1%
Mar	1,15	3396	3398	-525	2871	84,5%
Apr	1,17	2046	3927	1529	3575	91,0%
May	1,21	1746	4848	2741	4487	92,5%
Jun	1,21	3330	5289	1254	4584	86,7%
Jul	1,24	3995	5573	623	4618	82,9%
Aug	1,24	3995	5284	328	4323	81,8%
Sep	1,22	1896	4119	1814	3710	90,1%
Oct	1,18	2546	3294	279	2825	85,8%
Nov	1,16	3663	1958	-2277	1385	70,8%
Dec	1,13	3027	1403	-2022	1005	71,6%
Annual	1,18	36920	43210	-413	36507	84,5%
Average	-	3077	3601	-33	3044	-

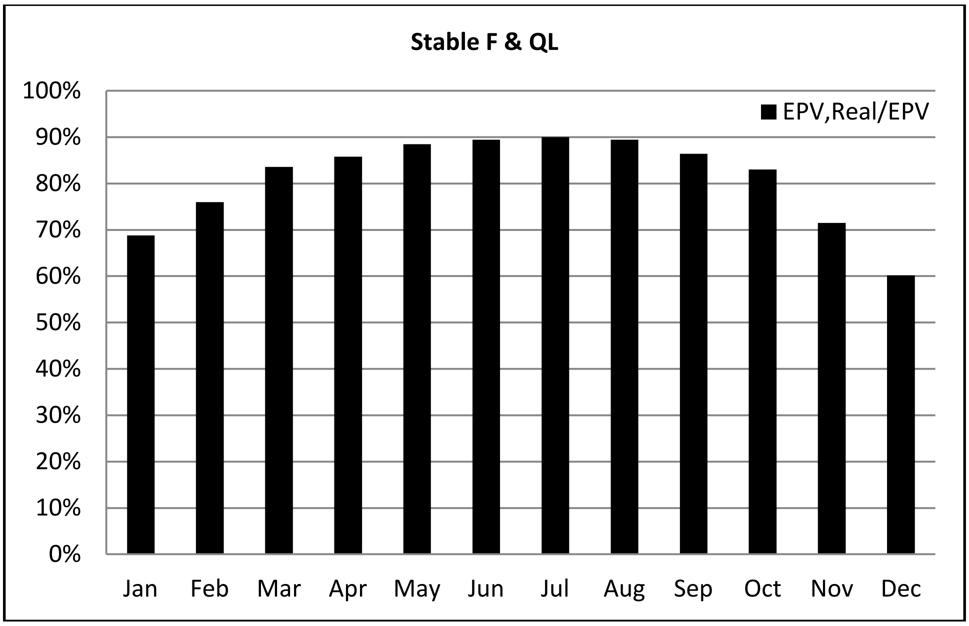


Graph 3.1: The annual average values in 20 years of operation of the PV System for the ratio $E_{PV,Real}$/ E_{PV}

To better understand how the ratio $E_{PV,Real}/E_{PV}$ is affected by the parameters F, Q_L & E_{PV}, below are presented in Graphs how the ratio $E_{PV,Real}/E_{PV}$ is affected by each parameter separately, keeping the other parameters constant.

1st Scenario:

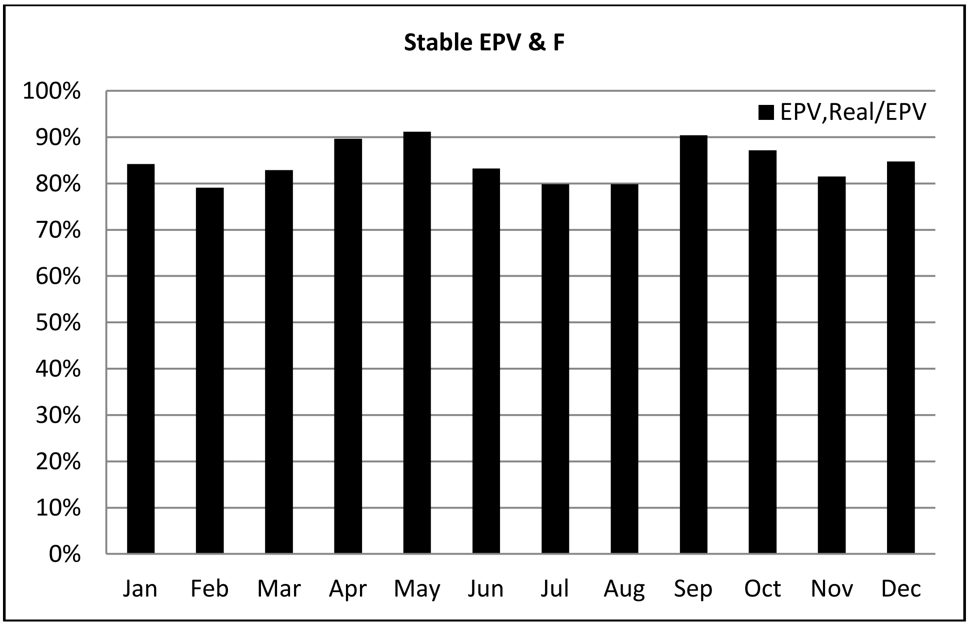
Stable for all months the parameters: F_m = 1.18 & $Q_{L,m}$ = 3077KWh (see Table 3.6).



Graph 3.2: The annual average values in 20 years of operation of the PV System for the ratio $E_{PV,Real}$/ E_{PV}. Stable for all months the parameters F & Q_L

2nd Scenario:

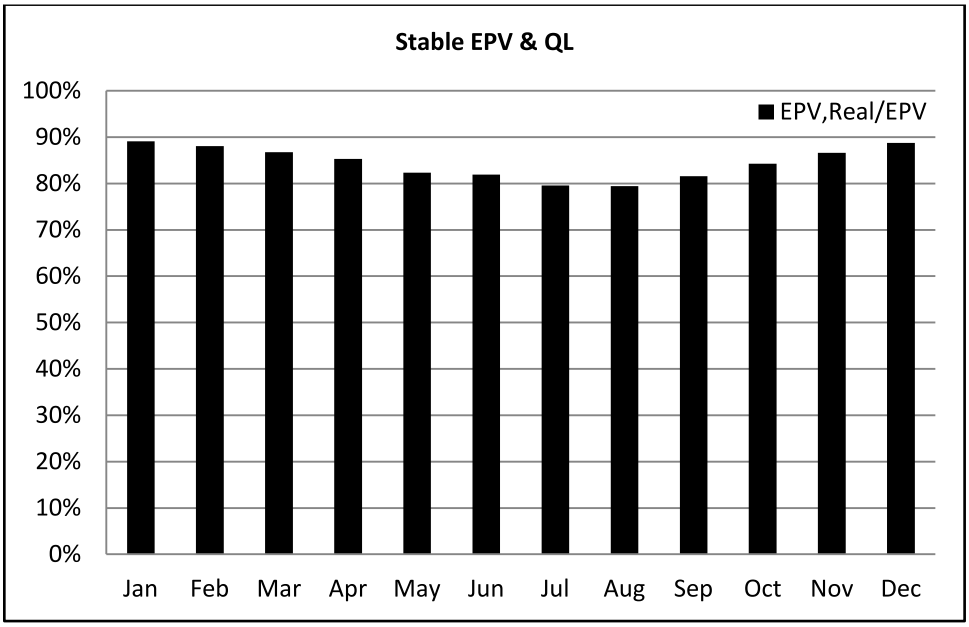
Stable for all months the parameters: $E_{PV,m}$ = 3601 KWh & F_m = 1.18 (see Table 3.6).



Graph 3.3: The annual average values in 20 years of operation of the PV System for the ratio $E_{PV,Real}$/ E_{PV}. Stable for all months the parameters E_{PV} & F

3rd Scenario:

Stable for all months the parameters: $E_{PV,m}$ = 3601KWh & $Q_{L,m}$ = 3077KWh (see Table 3.6).



Graph 3.4: The annual average values in 20 years of operation of the PV System for the ratio $E_{PV,Real}$/ E_{PV}. Stable for all months the parameters EPV & Q_L

Observing the Table 3.6 & Graphs 3.2, 3.3, 3.4 we end up at the following logic diagrams:

i. If E_{PV} [↑] → $E_{PV,Real}/E_{PV}$ [↑] & if E_{PV} [↓] → $E_{PV,Real}/E_{PV}$ [↓]
ii. If Q_L [↑] → $E_{PV,Real}/E_{PV}$ [↓] & if Q_L [↓] → $E_{PV,Real}/E_{PV}$ [↑]
iii. If F [↑] → $E_{PV,Real}/E_{PV}$ [↓] & if F [↓] → $E_{PV,Real}/E_{PV}$ [↑]

- 3rd Conclusion

In Table 2l & Graph 5s of Appendix III are shown the percentage of the excess or lack of electrical energy in relation to the annual electricity needs of the apartments (DE/Q_L). See monthly average values in 20 years of operation of the PV System.

Observing the Tables 2e, 2i, 2l & Graphs 5l, 5p, 5s of Appendix III, we notice that the months (January, February, March, November & December) where the needs for electric energy are large (Q_L [↑]) and the generation of electricity energy by the PV System is small (E_{PV} & $E_{PV,Real}$ [↓]) due to low available solar radiation (I), the ratio DE/Q_L decreases [↓] and indeed has negative values. I.e. the generated power by the PV System is not sufficient to cover the loads, so we have lack of energy with most striking example the months of February and November. This lack of energy will be purchased by PPC (purchase price → 0.23 €/KWh).

While the remaining months (April, May, June, July, August, September & October) where the generation of electricity energy by the PV System is large (E_{PV} & $E_{PV,Real}$ [↑]) due to high available solar radiation (I), the ratio DE/Q_L increases [↑] and has always positive values. I.e. the generated power by the PV System is sufficient to cover the loads and excess a percentage of this energy. I.e. we have excess of energy with most striking example the months of May and September that have relatively high available solar radiation (I) [↓] and the electrical loads are small Q_L [↓]. This Excess of Energy is sold to a neighboring company to cover a small part of its energy needs at sale price of 0.23 €/KWh.

Also, it is noticed that in the months June, July & August that prevails high solar radiation (I), the ratio DE/Q_L has positive values but relatively small compared to the available solar potential during these months.

This is because these months the apartments have large energy needs due to the hot weather that prevails and consequently the need for cooling of apartments with air-condition is large, Q_L [↑] (electricity consumption). For better understanding of the above, see Tables 2a, 2c, 2d, 2e, 2f, 2g, 2h, 2i, 2j, 2l & Graphs 5i, 5j, 5k, 5l, 5m, 5n, 5o, 5p, 5q, 5s of Appendix III.

More specifically, taking into account to above Tables and Graphs the monthly average values in 20 years of operation of the PV System, as well as the total values in 20 years of operation of the PV System, we notice that there is lack of energy in the following months:

i. In January we will have lack of energy -55.6%:
   a. DE = -1741 KWh → -400 € "for 1 year operation of the PV System".
   b. DE = -34814 KWh → -8007 € "for 20 years operation of the PV System".
ii. In February we will have lack of energy -61.8%:
   a. DE = -2564 KWh → -590 € "for 1 year operation of the PV System".
   b. DE = -51258 KWh → -11795 € "for 20 years operation of the PV System".
iii. In March we will have lack of energy -16.0%:
   a. DE = -543 KWh → -125 € "for 1 year operation of the PV System ".
   b. DE = -10854 KWh → -2496 € "for 20 years operation of the PV System".
iv. In November we will have lack of energy -62.1%:
   a. DE = -2273 KWh → -523 € "for 1 year operation of the PV System".
   b. DE = -45458 KWh → -10455 € "for 20 years operation of the PV System".
v. In December we will have lack of energy -67.3%:
   a. DE = -2036 KWh → -468 € "for 1 year operation of the PV System".
   b. DE = -40716 KWh → -9365 € "for 20 years operation of the PV System".

While, there is excess of energy in the following months:

i. In April we will have excess of energy 75.1%:
   a. DE = 1536 KWh → 353 € "for 1 year operation of the PV System".
   b. DE = 30719 KWh → 7065 € "for 20 years operation of the PV System".
ii. In May we will have excess of energy 157.6%:
   a. DE = 2752 KWh → 633 € "for 1 year operation of the PV System".
   b. DE = 55040 KWh → 12659 € "for 20 years operation of the PV System".
iii. In June we will have excess of energy 37.7%:
   a. DE = 1254 KWh → 288 € "for 1 year operation of the PV System".
   b. DE = 25086 KWh → 5770 € "for 20 years operation of the PV System".
iv. In July we will have excess of energy 15.5%:
   a. DE = 620 KWh → 143 € "for 1 year operation of the PV System".
   b. DE = 12403 KWh → 2853 € "for 20 years operation of the PV System".

4. TECHNO-ECONOMIC STUDY

4.1 LOANS

In our case study 105 Photovoltaic panels will be installed. Detailed the cost of the entire plant shown in the following table:

Table 4.5: Detailed costing of the entire plant

Object	Number of pieces	Price per piece [€]	Total price [€]
Photovoltaic panel	105	199,10	20.905,50
Inverter SMA 15	2	2.875,40	5.750,80
AC boxes	1	540,00	540,00
DC boxes	1	540,00	540,00
Basis of photovoltaic	105	30,00	3.150,00
Cables DC			360,00
Cables AC			480,00
Terminal/plugs			120,00
Cost of connection			350,00
Installation of equipment	105	36,00	3.780,00
Transportation costs			1.300,00
Total amount			37.276,30
V.A.T. (23%)			8.573,55
Total amount (with V.A.T.)			**45.849,85**
Cost/KW_p			1.339,67
Cost/KW_p (with V.A.T.)			1.647,79

Power per Photovoltaic panel: 265 W_p & $PV_{generator}$: 27,825 KW_p

4.2 ANNUAL PERCENTAGE RATE (APR) LOANS

The present value expression:

$$PV = annuity\ factor\ x\ S \tag{4.1}$$

where:

$$annuity\ factor = \frac{1-(1/1+I)^n}{I} \tag{4.2}$$

can be recast as follows:

$$amount\ of\ loan = annuity\ factor\ x\ annual\ repayment \tag{4.3}$$

and

$$annual\ repayment = \frac{total\ repayment}{n} \tag{4.4}$$

therefore:

$$amount\ of\ loan = \frac{annuity\ factor\ x\ total\ repayment}{n} \tag{4.5}$$

or

$$total\ repayment = \frac{amount\ of\ loan\ x\ n}{annuity\ factor} \tag{4.6}$$

The foreign capital of the investment is 35%. So, the amount of loan is 0,35·45.849,85 € = 16.047,45 €, the number of years of repayment is 10 years, and the interest rate is 7% (I=0.07) (O'Callaghan, 1992). Hence:

Amount of loan:	16.047,45 €
Number of years:	10
Interest rate:	0.07 (7%)
Annuity factor:	7.02
Total repayment:	22.847,96 €
Annual repayment:	2.284,80 €
Total repayment / Amount of loan:	1.42 (142%)
Annual repayment / Amount of loan:	0.142 (14,2%)

Table 4.6: Repayment schedule

Year	Loan outstanding [€]	Interest [€]
1	16047,45	1123,32
2	14885,98	1042,02
3	13643,20	955,02
4	12313,43	861,94
5	10890,57	762,34
6	9368,11	655,77
7	7739,09	541,74
8	5996,03	419,72
9	4130,95	289,17
10	2135,32	149,47
11	0,00	0,00

4.3 INVESTIGATION OF THE ECONOMIC VIABILITY OF ESTABLISHMENT AND OPERATION OF THE PV PLANT

According to Καλδέλης (2005), we will investigate the economic viability of establishment and operation of a PV plant 27.825 KW_p, in order to meet energy needs in a hotel complex in Zakynthos. For the examination of the issue we will assume:

- Annual rate of revaluation of energy: e = 5%
- Annual cost of money: i´ = 11%
- Initial disposal cost of energy: c_o = 0.23 €/KWh
- Average power factor: ω = 0.4
- Pursued technical availability: Δ = 90%
- Inflation: g = 4%
- For the purchase and installation of the PV (105x265KW_p) will be used:
  i. Equity capital: a = 25%
  ii. Government grant: c = 40%
- Pursued return equity capital: i = 8.12%
- Stable maintenance and operating costs of the installation "m_o": 250 €/year
- Annual increase at maintenance and operating costs of the installation: 1.00%
- Security of the installation "δ": 150 €/year

Considering that these figures will remain stable in the coming years and ignoring the effect of taxation will be calculated:

1. The initial cost of installation and the amount of equity and foreign capital of the investment.
2. The diachronic development of revenues of the investment, which exclusively gives the energy in the middle voltage of the electricity network of PPC.
3. The diachronic development of the investment cost (ignoring the variable cost of maintenance and operation, VC_n).
4. The payback time of the investment.
5. The diachronic change of the net profits of the investment (before taxes) at current and constant prices.
6. The doubling time of the initial capital.
7. The course of the economic efficiency of the investment.

Answer:

1. The initial cost of the installation is:

$IC_o = 45849.85€$ (see Table 1)

The equity capital is equal to:

$$a \cdot IC_o = 0.25 \cdot 45849.85€ = 11462.46€$$

Respectively, the government grant is equal to:

$$c \cdot IC_o = 0.4 \cdot 45849.85€ = 18339.94€$$

Apply:

$$a + b + c = 1 \rightarrow b = 0.35$$

Therefore, the foreign capital of the investment is given as:

$b \cdot IC_o = 0.35 \cdot 45849.85€ = 16047.45€$

2. For the estimation of the diachronic development of revenues of the investment, the equation used is:

$$R_n = \sum_{j=1}^{n} \left[\left(E_j \cdot c_j - \Phi_j \right) \cdot \prod_{m=j}^{m=n} (1 + i_m) \right] \tag{4.7}$$

in conjunction with the equations:

$$c_j = s_j \cdot c_{s_j} + \left(1 - s_j\right) \cdot c_{a_j} \tag{4.8}$$

$$c_{s_j} = c_{s_o} \cdot \prod_{k=1}^{k=j} \left(1 + e_{s_k}\right) \tag{4.9}$$

$$c_{a_j} = c_{a_o} \cdot \prod_{k=1}^{k=j} \left(1 + e_{a_k}\right) \tag{4.10}$$

and assuming that the values of "e" and "i" remain constant with time, while the effect of taxation ignored. In parallel, because all of the energy produced is sold to PPC, applies s=0. From the above arises the final equation of determination of the revenue:

$$R_n = R_o \cdot (1 + e) \cdot (1 + i)^{n-1} \cdot \left[1 + \frac{1 + e}{1 + i} + \ldots + \left(\frac{1 + e}{1 + i} \right)^{n-1} \right] \tag{4.11}$$

which is written for ease of arithmetic operations as follows:

$$R_n = R_o \cdot (1 + e) \cdot (1 + i)^n \cdot \frac{1 - \left(\frac{1 + e}{1 + i} \right)^n}{i - e} \tag{4.12}$$

wherein:

R_o or $E_{pv,real}$: the real energy delivered by the PV System after its degradation, in money (€/year). See Table 2j of Appendix III.

By substituting the appropriate figures in the equation (4.12) is filled the 3rd column of Table 1 of Appendix IV which presents the revenues of the investment (in €) the next twenty years. From the data of the calculations the estimated revenue of the investment in nominal prices, are located after ten years of operation of the investment in the levels of 157.623 € and after twenty years of operation of the investment in the levels of 512.532 €.

3. For the determination the diachronic development of the investment cost will be used the equation (4.13) in conjunction with the equations (4.14) & (4.15) as well as assuming that the variable costs of maintenance and operation can be ignored, therefore VC_n=0. Furthermore the various financial figures of equations (i, i′, g) remain stable over time.

$$C_n = IC_n + \cancel{VC_n} + FC_n \;\rightarrow\; C_n = IC_n + FC_n \tag{4.13}$$

The diachronic value after -n years of the initial installation cost "IC_o" is given as:

$$IC_n = a \cdot IC_o \cdot \prod_{l=1}^{l=n}(1+i_l) + b \cdot IC_o \cdot \prod_{l=1}^{l=n}(1+i'_l) + c \cdot IC_o \tag{4.14}$$

The stable maintenance and operating costs of the installation usually expressed as a percentage of the initial capital invested, adjusted every year by the annual inflation rate "g_i". So its diachronic development is:

$$FC_n = m \cdot IC_o \cdot [\prod_{l=1}^{l=n}(1+i_l) + \prod_{l=2}^{l=n}(1+i_l) \cdot (1+g_l)$$

$$+ \prod_{l=3}^{l=n-1}(1+i_l) \cdot \prod_{j=1}^{j=2}(1+g_j) + \ldots + \prod_{j=1}^{j=n-1}(1+g_j) \cdot (1+i_n)] \tag{4.15}$$

Based on the above the equation (4.15) is written as:

$$FC_n = m \cdot IC_o \cdot (1+g) \cdot (1+i)^{n-1} \cdot \left[1 + \frac{1+g}{1+i} + \cdots + \left(\frac{1+g}{1+i}\right)^{n-1}\right] \tag{4.16}$$

or for facilitation of arithmetical operations the equation (4.16) is written as:

$$FC_n = m \cdot IC_o \cdot (1+g) \cdot (1+i)^n \cdot \frac{1 - \left(\frac{1+g}{1+i}\right)^n}{i-g} \tag{4.17}$$

Also, it is known that:

- Stable maintenance and operating costs of the installation "m_o": 250 €/year
- Annual increase at maintenance and operating costs of the installation: 1.00%
- Security of the installation "δ": 150 €/year

Apply:

$$m = m_o + \delta \tag{4.18}$$

The results of the diachronic development of the coefficient "m" are presented in Table 2 of Appendix IV.

Substituting the numerical values in the above equations (4.14), (4.17) and (4.13) arise the columns (4), (6) and (7) respectively of Table 1 of Appendix IV while the column (9) in the same Table includes the total cost of the investment minus the government grant. Of the elements of calculations (see the 8th column of Table 1 and Graph 1 of Appendix IV) arises that the maintenance and operating costs initially constitutes a very small percentage of the total investment cost (1st year → 0.85%), but after ten years of operation of the investment reaches the levels of 7.79%, while after twenty years of operation of the investment reaches the levels of 12.68% of the total expenses of the investment.

4. Comparing the elements of 3rd and 7th column of Table 1 of Appendix IV is calculated based on the equation (4.19) the payback time of the investment which is estimated at 5.35 years. Respectively, subtracting from the expenses the participation of the government (9th column of Table 1 of Appendix IV), the final payback time of the investment is estimated at 3.55 years. This can be gauged if we observe in Graph 2 of Appendix IV the intersection point of the curve of the diachronic development of revenues of the investment (R_n) with the curves of the diachronic development of the investment cost with and without the participation of the government, (C_n) and ($C_n - c \cdot C_o$) respectively.

$$IC_n + \cancel{VC_n} + FC_n = R_n \rightarrow IC_n + FC_n = R_n \rightarrow C_n = R_n \tag{4.19}$$

wherein:

$$C_n = IC_n + \cancel{VC_n} + FC_n \rightarrow C_n = IC_n + FC_n \tag{4.20}$$

From the assessment of the payback time of the investment arises that the creation and operation of the PV unit is clearly sustainable, since the payback time is much lower than twenty years, which is the minimum value of the useful operating time of the unit. In parallel, the investment can be characterized and financially attractive, particularly in the case of government funding, as the payback time is lower than the 1/5 of the lifetime of the installation.

5. For the calculation of the net profits of the investment at current prices the equation used is (4.21) with the assumption that "VC_n=0", therefore:

$$G_n = R_n - IC_n - FC_n - \cancel{VC_n} \rightarrow G_n = R_n - IC_n - FC_n \rightarrow G_n = R_n - C_n \tag{4.21}$$

While for the calculation of the deflated profits it will be used and the equation:

$$\tilde{X}_j = \frac{X_j}{\prod_{k=1}^{k=j}(1+g_k)} \tag{4.22}$$

which for a constant price of inflation is written:

$$\tilde{G}_n = \frac{G_n}{(1+g)^n} \tag{4.23}$$

~: is used to describe deflated financial figures.

Substituting the numerical values of the 3rd and 7th column, are created the 10th and 11th column of Table 1 of Appendix IV. Of the elements of 10th and 11th column of the Table 1 and Graph 3 of Appendix IV we observe that the results until 5.35 year remain negative, which is consistent with the payback time of the company, while at the end of twenty years the expected profits reach 280.811,00 € at current prices or 128.158,00 € at constant present prices. Be added that in this analysis included the annual return on equity capital of the order of 8.12%.

6. For the calculation of the doubling time of the investment the equation used is the following:

- for current prices of inflation:

$$R_n - C_n = IC_o \qquad (4.24a)$$

- for constant prices of inflation:

$$\tilde{R}_n - \tilde{C}_n = IC_o \qquad (4.24b)$$

wherein:

- for current prices of inflation:

$$G_n = R_n - C_n \qquad (4.25a)$$

- for constant prices of inflation:

$$\tilde{G}_n = \tilde{R}_n - \tilde{C}_n \qquad (4.25b)$$

So, from the elements of the 10th column of Table 1 and Graph 3 of Appendix IV (see the curve of diachronic change of the net profits of the investment "before taxes" at current prices of inflation, G_n), the doubling time of the initial capital is estimated at 9.00 years approximately, i.e.:

$$n^{**} = 9.00\ years$$

While, from the elements of the 11th column of Table 1 and Graph 3 of Appendix IV (see the curve of diachronic change of the net profits of the investment (before taxes) at constant prices of inflation, $\tilde{G}_n$), the doubling time of the initial capital is estimated at 10.45 years approximately, i.e.:

$$n^{**\sim} = 10.45\ years$$

We observe that in both cases, because the doubling time is less than twenty years (even not taking into account the government grant) the investment is not just sustainable but economically attractive.

Also, observing the Graph 3 of Appendix IV, we see that the payback time for both cases is the same, 5.35 years.

7. This fact is confirmed and by the results of the 7th question, where is estimated the course of the economic efficiency of the investment according to the relation:

- for current prices of inflation:

$$\eta^* = \frac{G_n}{IC_o \cdot Y_n} \qquad (4.26a)$$

- for constant prices of inflation:

$$\eta^{*\sim} = \frac{\tilde{G}_n}{IC_o \cdot \tilde{Y}_n} \qquad (4.26b)$$

For safety reasons of exported conclusions the residual value of the investment often considered nil. Namely:

- for current prices of inflation:

$$Y_n = 0$$

- for constant prices of inflation:

$$\tilde{Y}_n = 0$$

so we have:

- for current prices of inflation:

$$\eta^* = \frac{G_n}{IC_o} \qquad (4.27a)$$

- for constant prices of inflation:

$$\eta^{*\sim} = \frac{\tilde{G}_n}{IC_o} \qquad (4.27b)$$

By substituting the appropriate figures in the equations (4.27a) & (4.27b) and knowing from Table 4.1 that the initial cost of the investment is:

$$IC_o = 45849.85€$$

arises the 12th and 13th column of Table 1 of Appendix IV.

- for current prices of inflation:

The elements of 12th column and from the Graph 4 of Appendix IV verify the payback time of the investment ($\eta^*=0.0 \rightarrow 5.35$ years) and the doubling time of the initial cost of the investment ($\eta^*=1.0 \rightarrow 9.00$ years), while at the end of the minimum period of useful operation of the investment show economic efficiency of the order of 612.5%.

- for constant prices of inflation:

The elements of 13th column and from the Graph 4 of Appendix IV verify the payback time of the investment ($\eta^{*\sim}=0.0 \rightarrow 5.35$ years) and the doubling time of the initial cost of the investment ($\eta^{*\sim}=1.0 \rightarrow 10.45$ years), while at the end of the minimum period of useful operation of the investment show economic efficiency of the order of 279.5%.

Also, observing the Graph 4 of Appendix IV, we see again that the payback time for both cases is the same, 5.35 years.

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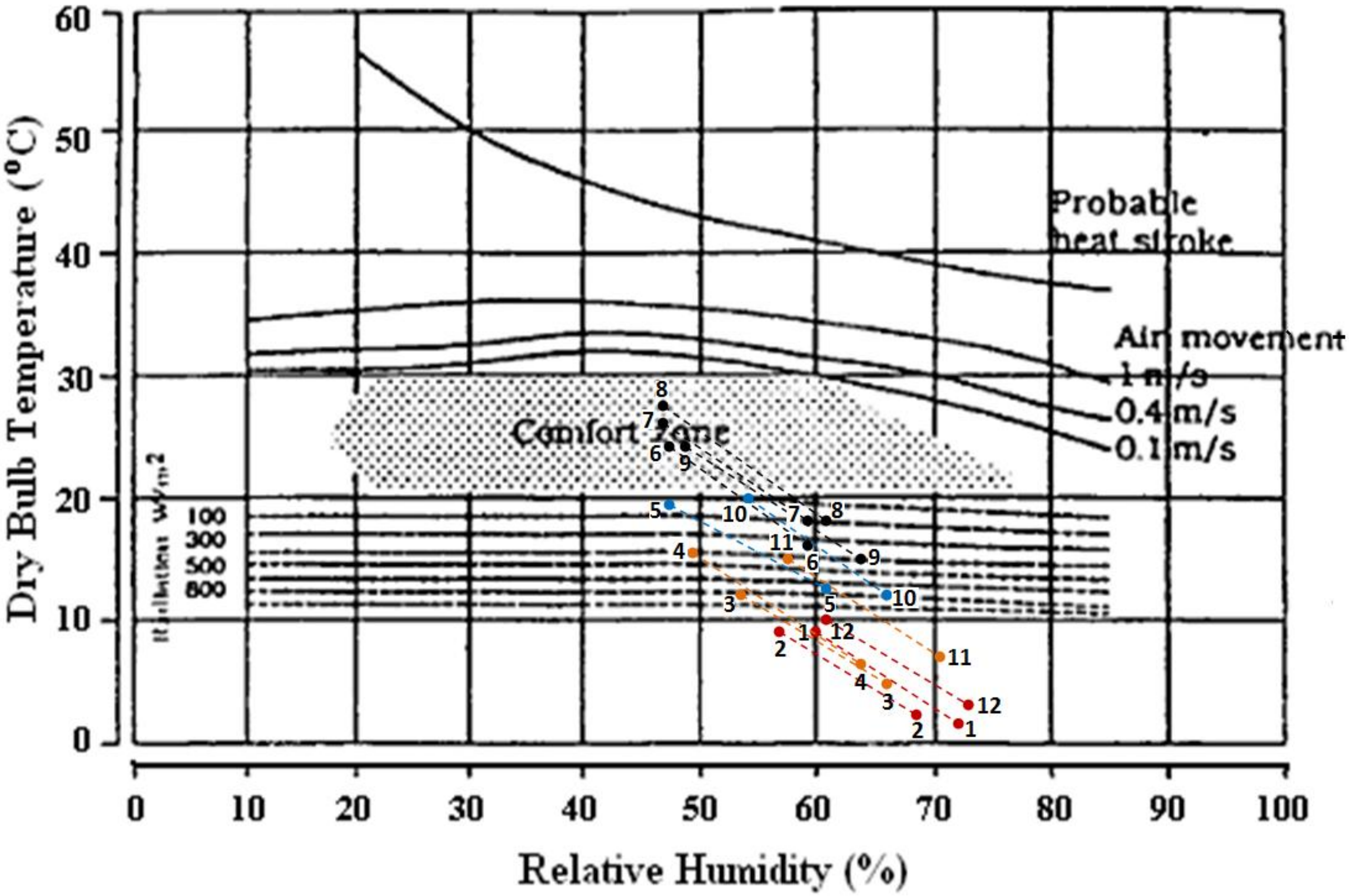
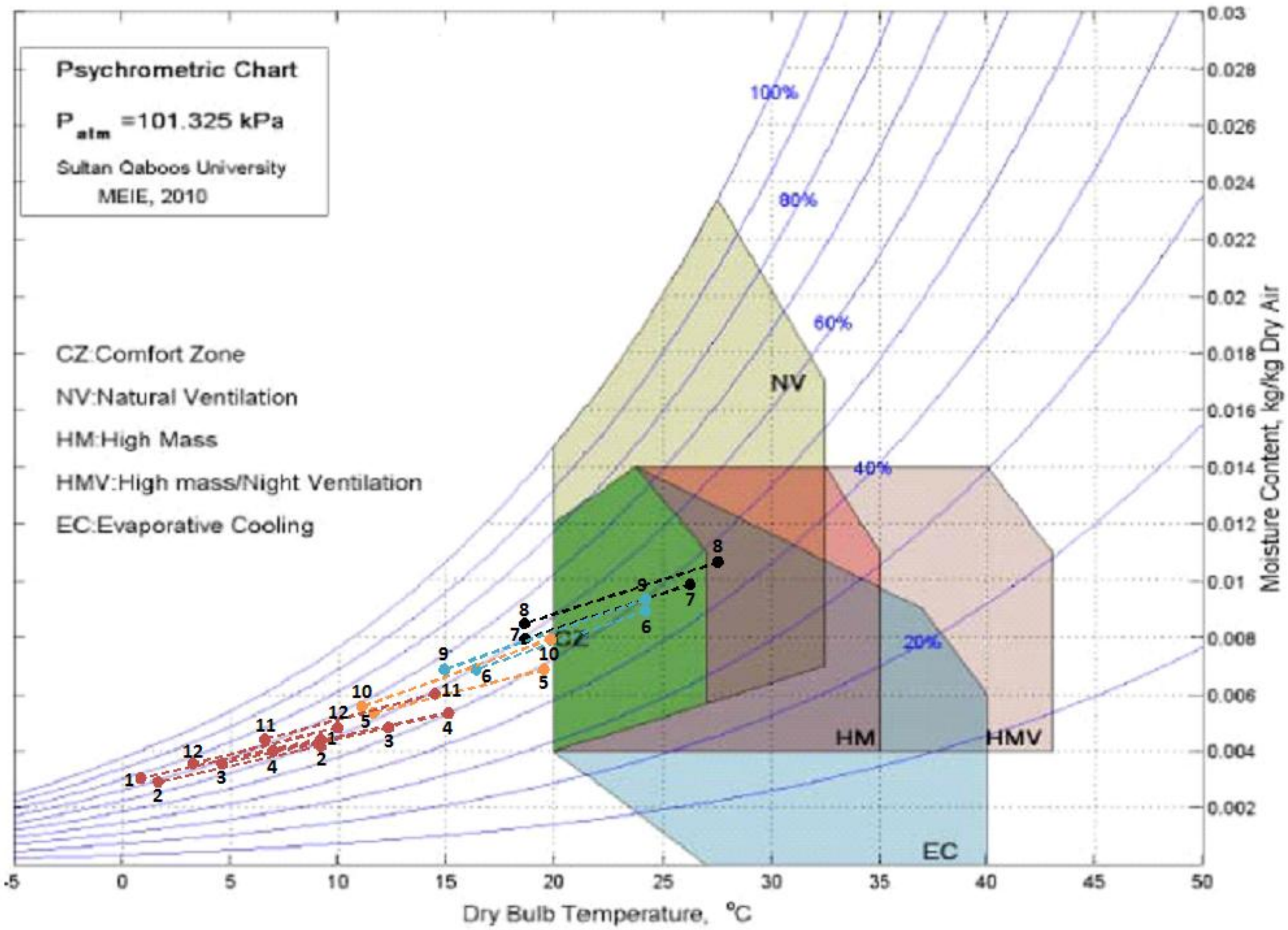
APPENDIX I

Table 1: Minimum and maximum values of Dry Bulb Temperature [°C] and Relative Humidity [%] from the database SODA.

Month	Dry Bulb Temperature °C		Relative Humidity %	
	Max	Min	Max	Min
Jan	9,0	1,5	71,5	60,0
Feb	9,0	2,0	68,5	57,0
Mar	12,5	4,5	66,5	53,5
Apr	15,5	7,0	63,5	49,5
May	19,5	12,0	60,5	47,5
Jun	24,0	16,5	59,5	47,0
Jul	26,5	18,5	59,5	46,5
Aug	27,5	18,5	61,0	46,5
Sep	24,0	15,0	63,0	49,0
Oct	20,0	11,5	66,5	54,0
Nov	14,5	7,0	70,5	58,0
Dec	10,0	3,5	72,0	61,0
Avearge	17,7	9,8	65,2	52,5



Graph 1: Bioclimatic Chart of Olgyay with the climatic conditions of Zakynthos (Al-Azri et al., 2012)



Graph 2: Bioclimatic Chart of Givoni with the climatic conditions of Zakynthos (Al-Azri et al., 2012)

APPENDIX II

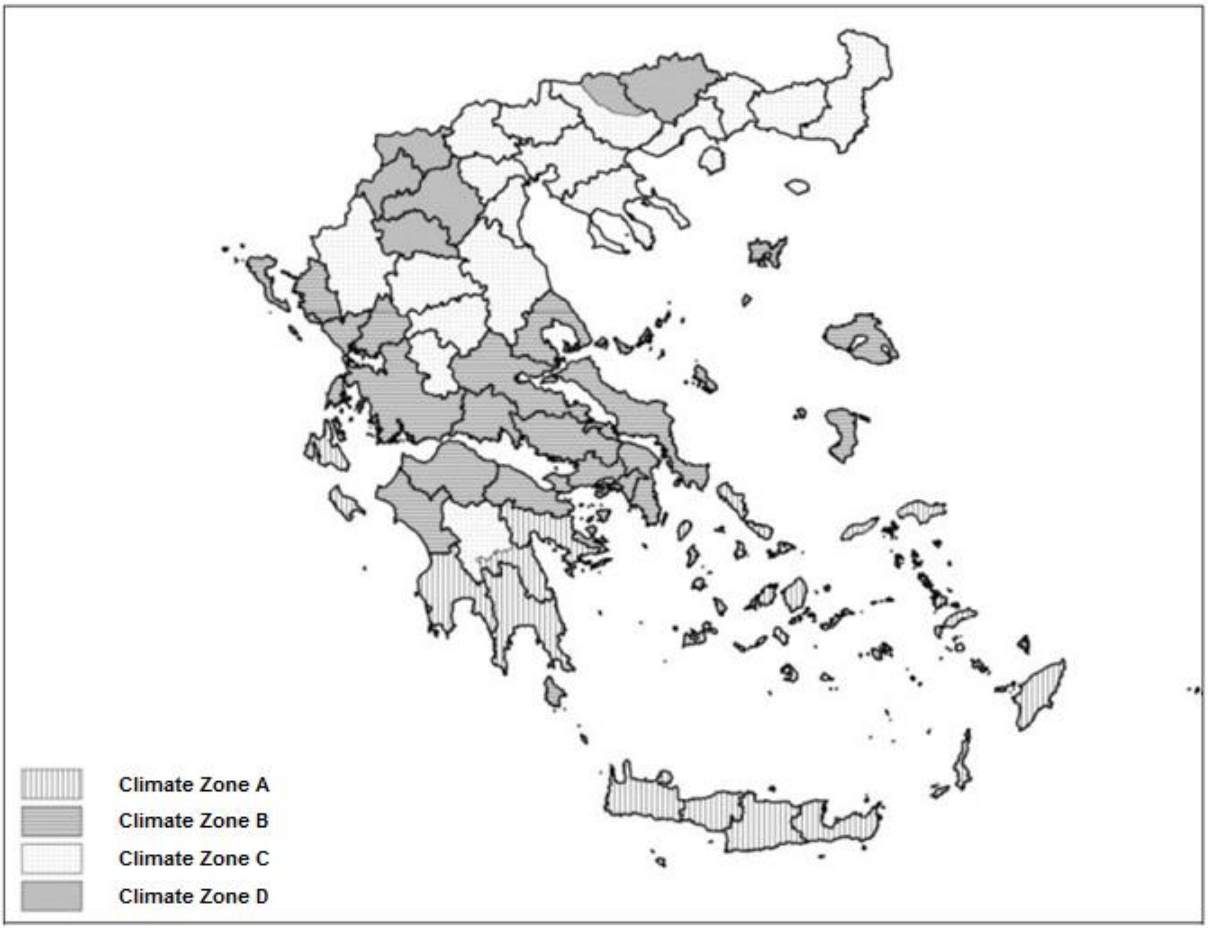


Figure 1: Schematic illustration of climate zones of Greek territory (T.O.T.E.E. 20701-1/2010, 2012 · T.O.T.E.E. 20701-3/2010, 2012)

Table 1: Maximum allowable mean Coefficient of Thermal Transmittance U_m of building for the four climatic zones in Greece (T.O.T.E.E. 20701-1/2010, 2012 · T.O.T.E.E. 20701-2/2010, 2010).

F/V m^{-1}	Maximum allowable mean coefficient of U_m							
	U_m [W/(m^{2}k)]				U_m [Kcal/(m^{2}h$^{\circ}$C)]			
	ZONE A	ZONE B	ZONE C	ZONE D	ZONE A	ZONE B	ZONE C	ZONE D
≤0,2	1,26	1,14	1,05	0,96	1,08	0,98	0,90	0,83
0,3	1,20	1,09	1,00	0,92	1,03	0,94	0,86	0,79
0,4	1,15	1,03	0,95	0,87	0,99	0,89	0,82	0,75
0,5	1,09	0,98	0,90	0,83	0,94	0,84	0,77	0,71
0,6	1,03	0,93	0,86	0,78	0,89	0,80	0,74	0,67
0,7	0,98	0,88	0,81	0,73	0,84	0,76	0,70	0,63
0,8	0,92	0,83	0,76	0,69	0,79	0,71	0,65	0,59
0,9	0,86	0,78	0,71	0,64	0,74	0,67	0,61	0,55
≥1,0	0,81	0,73	0,66	0,60	0,70	0,63	0,57	0,52

Table 2: Maximum allowable values of Coefficient of Thermal Transmittance of structural elements for the four climate zones in Greece (T.O.T.E.E. 20701-1/2010, 2012).

Structural element	Symbol	Coefficient of Thermal Transmittance [W/(m^{2}k)]				Coefficient of Thermal Transmittance [Kcal/(m^{2}h$^{\circ}$C)]			
		Climate zone				Climate zone			
		Α	Β	Γ	Δ	Α	Β	Γ	Δ
Exterior horizontal or inclined surface in contact with the outside air (ceilings).	U_{V_D}	0,50	0,45	0,40	0,35	0,43	0,39	0,34	0,30
Exterior walls in contact with the outside air.	U_{V_W}	0,60	0,50	0,45	0,40	0,52	0,43	0,39	0,34
Floors in contact with the outside air (piloti).	U_{V_DL}	0,50	0,45	0,40	0,35	0,43	0,39	0,34	0,30
Floors in contact with the ground or enclosed unheated spaces.	U_{V_G}	1,20	0,90	0,75	0,70	1,03	0,77	0,65	0,60
Walls in contact with the ground or unheated spaces.	U_{V_WE}	1,50	1,00	0,80	0,70	1,29	0,86	0,69	0,60
Openings (windows, balcony doors etc.)	U_{V_F}	3,20	3,00	2,80	2,60	2,75	2,58	2,41	2,24
Glass facades of buildings non opened and partially opened.	U_{V_GF}	2,20	2,00	1,80	1,80	1,89	1,72	1,55	1,55

Table 3: Typical values of the Coefficient of Thermal Transmittance of glass pane U_g, which can be used to determine the Coefficient of Thermal Transmittance of window frames during energy audit of buildings (T.O.T.E.E. 20701-1/2010, 2012).

A/A	Type of glass pane	U_g	
		[(W/m²K)]	[Kcal/(m²h°C)]
1	Single glass pane	5,70	4,90
2	Twins glass pane with air gap 6mm	3,30	2,84
3	Twins glass pane with air gap 12mm	2,80	2,41
4	Twins glass pane with air gap 6mm and with coating membrane low emissivity (ε=0,10)	2,60	2,24
5	Twins glass pane with air gap 12mm and with coating membrane low emissivity (ε=0,10)	1,80	1,55
6	Glass blocks	3,50	3,01

Table 4: Typical values of the Coefficient of Thermal Transmittance of frame U_f, which can be used to determine the Coefficient of Thermal Transmittance of window frames during energy audit of buildings (T.O.T.E.E. 20701-1/2010, 2012).

A/A	Frame type	U_f	
		[(W/m²K)]	[Kcal/(m²h°C)]
1	Metal frame without thermal break	7,00	6,02
2	Metal frame with thermal break 12mm	3,50	3,01
3	Metal frame with thermal break 24mm	2,80	2,41
4	Synthetic frame	2,80	2,41
5	Wooden frame	2,20	1,89

Table 5: Values of thermal conductivity (design values), specific heat capacity and resistance coefficient to water vapor diffusion for various building materials (T.O.T.E.E. 20701-2/2010, 2010).

A/A	Building materials	Density	Thermal conductivity coefficient. Design values.	Specific heat capacity	Resistance coefficient to water vapor diffusion	
		ρ	λ	c_p	μ	
		kg/m^3	W/(mK)	J/(kgK)	dry	fluid
1	Lime mortar	1800	0,87	1000	15	
2	Brickwork with punched baked bricks	1500	0,51	1000	5 — 10	
3	Reinforced concrete low quality (old type B120)		1,51			
4	Tile roof		d/λ = 0,23			
5	Coating tiles		0,9			
6	Cement for mortars, cement coating	2000	1,4	1100	25 — 35	
7	Expanded polystyrene in plates		0,033 — 0,038	1500	20 — 100	

Table 6: Conventional way of calculating of the area occupied by the bearing structure of the building as a percentage on the surface of its face in case it is not possible the imprinting of the bearing structure (T.O.T.E.E. 20701-1/2010, 2012).

Year of publishing of building permit	Type of building	Number of floors	
		up to 5	>5
Before 1981	Corner building	15%	22%
	Non corner building	25%	30%
1981 to 1999	Corner building	18%	25%
	Non corner building	30%	35%

Table 7: Analytical calculation of the surface area of openings (see floor plans at APPENDIX V).

Opening	Total number of openings per opening and per floor			Total number of openings per opening
	Ground floor	1st floor	Attic	
F_1	6	6	0	12
F_2	6	6	0	12
F_3	10	10	0	20
F_4	0	0	6	6
F_5	0	0	6	6
F_6	0	0	6	6
Total	22	22	18	62

Opening	Length (m)	Height (m)	Total opening surface (m^2)	Total glass pane surface (m^2)	Total aluminum surface (m^2)	Total opening surface per floor (m^2)			Total opening surface per opening (m^2)
						Ground floor	1st floor	Attic	
F_1	0,90	2,20	1,98	1,32	0,66	11,88	11,88	0,00	23,76
F_2	0,55	0,65	0,36	0,18	0,18	2,15	2,15	0,00	4,29
F_3	1,25	2,30	2,88	2,15	0,73	28,75	28,75	0,00	57,50
F_4	0,90	1,90	1,71	1,13	0,58	0,00	0,00	10,26	10,26
F_5	0,55	0,50	0,28	0,13	0,15	0,00	0,00	1,65	1,65
F_6	1,25	1,90	2,38	1,75	0,63	0,00	0,00	14,25	14,25
Total	-	-	-	-	-	42,78	42,78	26,16	111,71

Glass pane	Total glass pane surface per opening and per floor (m^2)			Total glass pane surface per opening (m^2)
	Ground floor	1^{st} floor	Attic	
$F1_1$	7,92	7,92	0,00	15,84
$F1_2$	1,09	1,09	0,00	2,19
$F1_3$	21,50	21,50	0,00	43,00
$F1_4$	0,00	0,00	6,76	6,76
$F1_5$	0,00	0,00	0,75	0,75
$F1_6$	0,00	0,00	10,50	10,50
Total	30,52	30,52	18,01	79,05
Glass pane/Opening	71%	71%	69%	71%

Aluminum	Total aluminum surface per opening and per floor (m^2)			Total glass pane surface per opening (m^2)
	Ground floor	1^{st} floor	Attic	
$F2_1$	3,96	3,96	0,00	7,92
$F2_2$	1,05	1,05	0,00	2,10
$F2_3$	7,25	7,25	0,00	14,50
$F2_4$	0,00	0,00	3,50	3,50
$F2_5$	0,00	0,00	0,90	0,90
$F2_6$	0,00	0,00	3,75	3,75
Total	12,26	12,26	8,15	32,67
Aluminum/Opening	29%	29%	31%	29%

Table 7: PivotTable with geometric and functional elements of building (see floor plans of APPENDIX V).

Persons	22	/day
Days of Operation Annually (For heating)	213	/year
Hours of Operation Daily (mean value)	3	/day
Hours of Operation Annually	639	/year
Floors	2	
Length	22,24	m
Width	7,96	m
Height of Floor	3,1	m
Surface of floor	**177,03**	**m^2**
Volume of floor	**548,79**	**m^3**
Surface of floor (Attic)	**177,03**	**m^2**
Height h1 (Attic)	2,11	m^2
Height h2 (Attic)	1,27	m^2
Volume V1 (Attic)	373,53	m^3
Volume V2 (Attic)	112,41	m^3
Total Volume (Attic)	**485,95**	**m^3**
Total Surface of floors of building (A)	**531,09**	**m^2**
Volume of building (V)	**1583,54**	**m^3**
Perimeter of the building	68,32	m
Surface of Exterior Masonry and Openings (Ground Floor)	211,79	m^2
Surface of Exterior Masonry and Openings (1st Floor)	211,79	m^2
Surface of Exterior Masonry and Openings (Attic)	144,16	m^2
Surface of Exterior Masonry and Openings (Attic)	28,24	m^2
Total Surface of Exterior Masonry and Openings (Etot)	**595,98**	**m^2**
Surface of exterior walls (E1: Ground Floor)	130,89	m^2
Surface of exterior walls (E2: 1st Floor)	130,89	m^2
Surface of exterior walls (E3: Attic)	115,21	m^2
Total Surface of exterior walls	**377,00**	**m^2**
Percentage of Surface of exterior walls [10cm]	88,4	%
Percentage of Surface of exterior walls [20cm]	11,6	%
Surface of exterior walls (E1: Ground Floor) [20cm]	15,17	m^2
Surface of exterior walls (E2: 1st Floor) [20cm]	15,17	m^2
Surface of exterior walls (E3: Attic) [20cm]	13,36	m^2
Total Surface of exterior walls [20cm]	**43,70**	**m^2**
Surface of exterior walls (E1: Ground Floor) [10cm]	115,72	m^2
Surface of exterior walls (E2: 1st Floor) [10cm]	115,72	m^2
Surface of exterior walls (E3: Attic) [10cm]	101,85	m^2
Total Surface of exterior walls [10cm]	**333,29**	**m^2**

Exterior bolster-beams as a percentage of the surface of the face of the building	18	%
Surface of exterior bolster-beams (Ground Floor)	38,12	m^2
Surface of exterior bolster-beams (1st Floor)	38,12	m^2
Surface of exterior bolster-beams (Attic)	31,03	m^2
Total Surface of exterior bolster-beams	**107,28**	$\mathbf{m^2}$
Surface of Openings (Ground Floor)	42,78	m^2
Surface of Openings (1st Floor)	42,78	m^2
Surface of Openings (Attic)	26,16	m^2
Total Surface of Openings	**111,71**	$\mathbf{m^2}$
Percentage of window area	19	%
Surface of Glass pane (Ground Floor)	30,52	m^2
Surface of Glass pane (1st Floor)	30,52	m^2
Surface of Glass pane (Attic)	18,01	m^2
Total Surface of Glass pane	**79,05**	$\mathbf{m^2}$
Surface of Aluminum (Ground Floor)	12,26	m^2
Surface of Aluminum (1st Floor)	12,26	m^2
Surface of Aluminum (Attic)	8,15	m^2
Total Surface of Aluminum	**32,67**	$\mathbf{m^2}$
Area of Roof	187,22	m^2
Total Surface of Floor standing and Roof	**364,25**	$\mathbf{m^2}$
Building envelope (F)	**960,23**	$\mathbf{m^2}$
(F/V)	**0,61**	$\mathbf{m^{-1}}$

Table 8: Study of thermal insulation of the building in accordance with the R.En.E.B. (see Tables 1-8 at APPENDIX II 8 & floor plans at APPENDIX V).

Study of thermal insulation of the building in accordance with the R.En.E.B.

A General information of building

1	Subject	Apartments for Rent in Zakynthos
2	Address	Zakynthos
3	Owner	-
4	Studier	Dimitrios Chountalos
5	Altitude	7,9
6	Zone	A

B Specific informations of the building

s.n	Type of surface	Brief name	Ground Floor	1st Floor	Attic								Total
1	Surface of exterior walls (20cm)	F_{W1}	15,17	15,17	13,36								43,70
2	Surface of exterior walls (10cm)	F_{W2}	115,72	115,72	101,85								333,29
3	Surface of exterior bolster-beams	F_{W3}	38,12	38,12	31,03								107,28
4	Surface of Openings (Glass pane)	F_{F1}	30,52	30,52	18,01								79,05
5	Surface of Openings (Aluminum)	F_{F2}	12,26	12,26	8,15								32,67
6	Surface of ceiling, doma, roof	F_{D1}			187,22								187,22
7	Surface of ceiling under roof which is not thermally insulated	F_{D2}											0,00
8	Floor surface over an enclosed non heated space	F_{G1}											0,00
9	Floor surface up on the ground	F_{G2}	177,03										177,03
10	Floor surface up on open space	F_{DL}											0,00
11	Departments which bordering with low temperature spaces	F_{AB1}											0,00
		F_{AB2}											0,00

	Total external building surface	F	388,82	211,79	359,62								960,23
	Volume of the building	V	548,79	548,79	485,95								1583,54
	Ratio	F / V	**0,6**										
C	**Maximum allowable value of U_m**												
	Maximum allowable value of U_m	$U_{m,max}$	**1,03**	W/(m²k)									

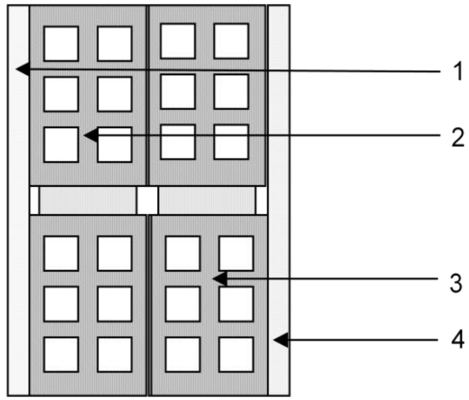
Thermal insulation of buildings in accordance with the R.En.E.B.		
Table 1	Subject	Apartments for Rent in Zakynthos
	Address	Zakynthos
	Owner	-
No. Leaf 1.1	Studier	Dimitrios Chountalos
	Altitude	7,9
	Zone	A

Calculation of thermal insulation of structural elements

Structural element : **Exterior masonry**

1. Calculation of thermal resistance 1/Λ

s.n.	1	2	3	4=(2*3)	5	6=(3:5)
	Layers of structural element	Density Kg/m^3	Thickness d m	Weight of the surface Kg/m^2	Thermal conductivity coefficient λ [W/(mK)]	d/λ $[(m^2K)/W]$
1	Lime mortar		0,015		0,870	0,017
2	Brickwork with punched baked bricks		0,085		0,510	0,167
3	Brickwork with punched baked bricks		0,085		0,510	0,167
4	Lime mortar		0,015		0,870	0,017
5						0,000
6						0,000
7						0,000
8						0,000
9						0,000
10						0,000
			0,200			0,368



Total thermal resistance 1/Λ =	**0,368**	$(m^2K)/W$

	2. Resistances of thermal transition		
s.n.	Structural element	R_i $[(m^2K)/W]$	R_a $[(m^2K)/W]$
1	Exterior walls and windows (towards outside air)	0,13	0,04
2	Wall which bordering with unheated space	0,13	0,13
3	Wall in contact with the ground	0,13	0,00
4	Roof, chamber (rising heat flow)	0,10	0,04
5	Ceiling bordered with unheated space (rising heat flow)	0,10	0,10
6	Carpeted above of open passage (piloti) (downward heat flow)	0,17	0,04
7	Carpeted above of unheated space (downward heat flow)	0,17	0,17
8	Carpeted in contact with the ground	0,17	0,00
	Specifying magnitude	**0,13**	**0,04**

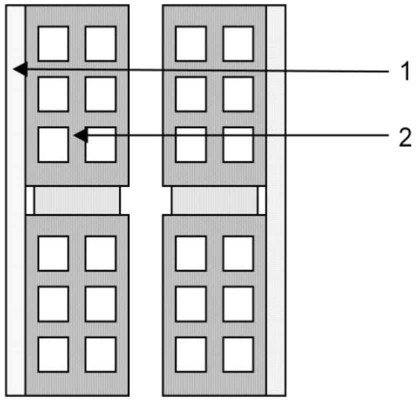
3.Calculation of Coefficient of thermal transmittance U

Ri	0,130
R_{Λ}	0,368
R_a	0,040
R_{tot}	0,538

1. Coefficient of thermal transmittance U [(W/m^{2}K)] =	**1,859**
2. Max Coeffic. of thermal transmittance U [(W/m^{2}K)] =	0,600
3. Difference	-1,259

Needs improvement!

Thermal insulation of buildings in accordance with the R.En.E.B.						
Table 1			Subject	Apartments for Rent in Zakynthos		
			Address	Zakynthos		
			Owner	-		
No. Leaf 1.2			Studier	Dimitrios Chountalos		
			Altitude	7,9		
			Zone	A		
Calculation of thermal insulation of structural elements						
Structural element :	**Masonry with double shell, with gap between those, inside which are towed the sheets of the opening**					
1. Calculation of thermal resistance 1/Λ						
	1	2	3	4=(2*3)	5	6=(3:5)
s.n.	Layers of structural element	Density Kg/m^3	Thickness d m	Weight of the surface Kg/m^2	Thermal conductivity coefficient λ λ [W/(mK)]	d/λ [(m^{2}K)/W]
1	Lime mortar		0,015		0,870	0,017
2	Brickwork with punched baked bricks		0,085		0,510	0,167
3						0,000
4						0,000
5						0,000
6						0,000
7						0,000
8						0,000
9						0,000
10						0,000
			0,100			0,184



Total thermal resistance 1/Λ =	**0,184**	(m²K)/W

2. Resistances of thermal transition

s.n.	Direction of heat flow	R_i [(m²K)/W]	R_a [(m²K)/W]
1	Horizontal heat flow	0,13	0,04
2	Vertical thermal upflow	0,10	0,04
3	Vertical thermal downflow	0,17	0,04
	Specifying magnitude	**0,13**	**0,04**

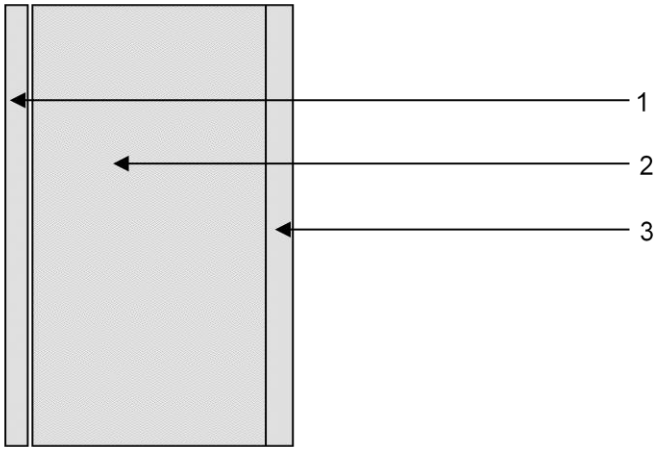
3.Calculation of coefficient of thermal transmittance U

Ri	0,130
$R_Λ$	0,184
Ra	0,040
R_{tot}	0,354

1. Coefficient of thermal transmittance U [(W/m2K)] =	**2,826**
2. Max Coeffic. of thermal transmittance U [(W/m2K)] =	0,600
3. Difference	-2,226

Needs improvement!

Thermal insulation of buildings in accordance with the R.En.E.B.						
Table 1			SUBJECT	Apartments for Rent in Zakynthos		
			ADDRESS	Zakynthos		
			OWNER	-		
No. Leaf 1.3			STUDIER	Dimitrios Chountalos		
			ALTITUDE	7,9		
			ZONE	A		
Calculation of thermal insulation of structural elements						
Structural element :	**Exterior beam - brickwork - column**					
1. Calculation of thermal resistance 1/Λ						
1		2	3	4=(2*3)	5	6=(3:5)
s.n.	Layers of structural element	Density Kg/m³	Thickness d m	Weight of the surface Kg/m²	Thermal conductivity coefficient λ λ [W/(mK)]	d/λ [(m²K)/W]
1	Lime mortar		0,015		0,870	0,017
2	Reinforced concrete low quality (old type B120)		0,270		1,510	0,179
3	Lime mortar		0,015		0,870	0,017
4						0,000
5						0,000
6						0,000
7						0,000
8						0,000
9						0,000
10						0,000
			0,300			0,213



Total thermal resistance 1/Λ =	**0,213**	$(m^2K)/W$

	2. Resistances of thermal transition		
s.n.	Structural element	R_i $[(m^2K)/W]$	R_a $[(m^2K)/W]$
1	Exterior walls and windows (towards outside air)	0,13	0,04
2	Wall which bordering with unheated space	0,13	0,13
3	Wall in contact with the ground	0,13	0,00
4	Roof, chamber (rising heat flow)	0,10	0,04
5	Ceiling bordered with unheated space (rising heat flow)	0,10	0,10
6	Carpeted above of open passage (piloti) (downward heat flow)	0,17	0,04
7	Carpeted above of unheated space (downward heat flow)	0,17	0,17
8	Carpeted in contact with the ground	0,17	0,00
	Specifying magnitude	**0,13**	**0,04**

3.Calculation of coefficient of thermal transmittance U

Ri	0,130
R_{Λ}	0,213
Ra	0,040
R_{tot}	0,383

1. Coefficient of thermal transmittance	U [(W/m2K)] =	**2,609**
2. Max Coeffic. of thermal transmittance	U [(W/m2K)] =	0,600
3. Difference		-2,009

Needs improvement!

Thermal insulation of buildings in accordance with the R.En.E.B.

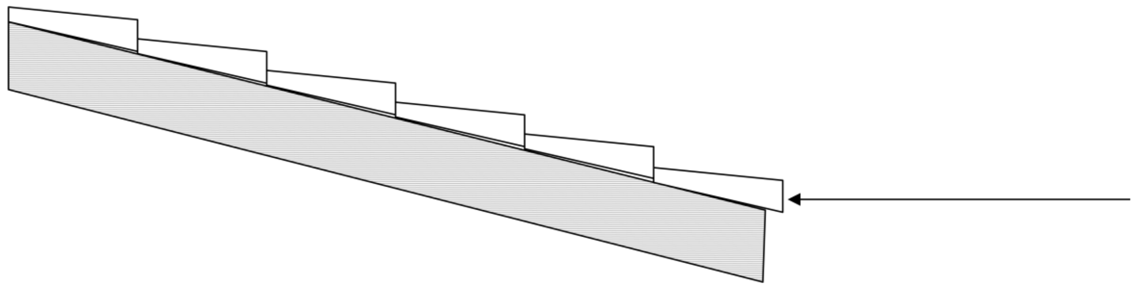
Table 1	Subject	Apartments for Rent in Zakynthos	
	Address	Zakynthos	
	Owner	-	
No. Leaf 1.4	Studier	Dimitrios Chountalos	
	Altitude	7,9	
	Zone	A	

Calculation of thermal insulation of structural elements

Structural element : **Tile roof**

1. Calculation of thermal resistance 1/Λ

s.n.	1	2	3	4=(2*3)	5	6=(3:5)
	Layers of structural element	Density Kg/m^3	Thickness d m	Weight of the surface Kg/m^2	Thermal conductivity coefficient λ λ [W/(mK)]	d/λ [(m^{2}K)/W]
1	Tile roof					0,230
2						0,000
3						0,000
4						0,000
5						0,000
6						0,000
7						0,000
8						0,000
9						0,000
10						0,000
			0,000			0,230



Total thermal resistance 1/Λ =	**0,230**	$(m^2K)/W$

	2. Resistances of thermal transition		
s.n.	Structural element	R_i $[(m^2K)/W]$	R_a $[(m^2K)/W]$
1	Exterior walls and windows (towards outside air)	0,13	0,04
2	Wall which bordering with unheated space	0,13	0,13
3	Wall in contact with the ground	0,13	0,00
4	Roof, chamber (rising heat flow)	0,10	0,04
5	Ceiling bordered with unheated space (rising heat flow)	0,10	0,10
6	Carpeted above of open passage (piloti) (downward heat flow)	0,17	0,04
7	Carpeted above of unheated space (downward heat flow)	0,17	0,17
8	Carpeted in contact with the ground	0,17	0,00
	Specifying magnitude	**0,10**	**0,04**

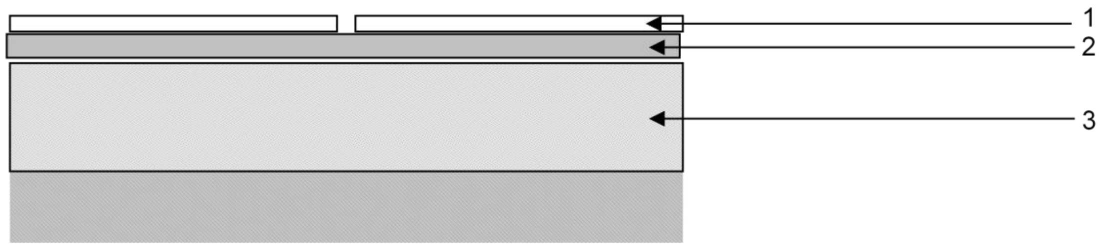
3.Calculation of coefficient of thermal transmittance U

Ri	0,100
R_{Λ}	0,230
Ra	0,040
R_{tot}	0,370

1. Coefficient of thermal transmittance	U [(W/m2K)] =	**2,703**
2. Max Coeffic. of thermal transmittance	U [(W/m2K)] =	0,500
3. Difference		-2,203

Needs improvement!

Thermal insulation of buildings in accordance with the R.En.E.B.						
Table 1			Subject	Apartments for Rent in Zakynthos		
			Address	Zakynthos		
			Owner	-		
No. Leaf 1.5			Studier	Dimitrios Chountalos		
			Altitude	7,9		
			Zone	A		
Calculation of thermal insulation of structural elements						
Structural element :		**Floor up on the ground**				
1. Calculation of thermal resistance 1/Λ						
1		2	3	4=(2*3)	5	6=(3:5)
s.n.	Layers of structural element	Density Kg/m^3	Thickness d m	Weight of the surface Kg/m^2	Thermal conductivity coefficient λ λ [W/(mK)]	d/λ [(m^{2}K)/W]
1	Coating tiles		0,010		0,900	0,011
2	Cement for mortars, cement coating		0,020		1,400	0,014
3	Reinforced concrete low quality (old type B120)		0,170		1,510	0,113
4						0,000
5						0,000
6						0,000
7						0,000
8						0,000
9						0,000
10						0,000
			0,200			0,138



Total thermal resistance 1/Λ =	**0,138**	$(m^2K)/W$

	2. Resistances of thermal transition		
s.n.	Structural element	R_i [$(m^2K)/W$]	R_a [$(m^2K)/W$]
1	Exterior walls and windows (towards outside air)	0,13	0,04
2	Wall which bordering with unheated space	0,13	0,13
3	Wall in contact with the ground	0,13	0,00
4	Roof, chamber (rising heat flow)	0,10	0,04
5	Ceiling bordered with unheated space (rising heat flow)	0,10	0,10
6	Carpeted above of open passage (piloti) (downward heat flow)	0,17	0,04
7	Carpeted above of unheated space (downward heat flow)	0,17	0,17
8	Carpeted in contact with the ground	0,17	0,00
	Specifying magnitude	**0,17**	**0,00**

3.Calculation of coefficient of thermal transmittance U

R_i	0,170
R_Λ	0,138
R_a	0,000

R_{tot}	0,308

1. Coefficient of thermal transmittance U [(W/m2K)] =	**3,247**
2. Max Coeffic. of thermal transmittance U [(W/m2K)] =	1,200
3. Difference	-2,047

Needs improvement!

Thermal insulation of buildings in accordance with the R.En.E.B.

Table 2		Subject	Apartments for Rent in Zakynthos
		Address	Zakynthos
		Owner	-
No. Leaf 2.1		Studier	Dimitrios Chountalos
		Altitude	7,9
		Zone	A

Calculation of thermal insulation of floor — **Ground Floor**

Proof : $U_m(w,F)=(\Sigma(U_w*F_w)+\Sigma(U_f*F_f))/\Sigma(F_w+F_f) <=$ 1,03 $[(W/m^2K)]$

Floor : Ground Floor

s.n.	1 Structural element	2 Name	3 Brief name	4 Surface F m^2	5 Coefficient of thermal transmittance U $[(W/m^2K)]$		6 U*F [(W/K)]
1	Wall	Exterior wall (20cm)	W1	15,174	No. Leaf 1.1	1,859	28,214
		EXTERIOR WALL (10cm)	W2	115,720	No. Leaf 1.2	2,826	326,979
		Beam - brickwork - column	W3	38,123	No. Leaf 1.3	2,609	99,461
2	Opening	Single glass pane	F1	30,516	Table 1α	5,700	173,939
		Metal frame with thermal break 24mm	F2	12,259	Table 2α	7,000	85,816
			F3				0,000
				211,792			714,409
3	$U_m(w,f)$	$U_m(w,f)$ =	**3,373**	<= 1,03	$[(W/m^2K)]$	**Needs improvement!**	

Thermal insulation of buildings in accordance with the R.En.E.B.							
Table 2			Subject	Apartments for Rent in Zakynthos			
			Address	Zakynthos			
			Owner	-			
No. Leaf 2.2			Studier	Dimitrios Chountalos			
			Altitude	7,9			
			Zone	A			
Calculation of thermal insulation of floor				**1st Floor**			
Proof :		$U_m(w,F)=(\Sigma(U_w*F_w)+\Sigma(U_f*F_f))/\Sigma(F_w+F_f) <=$		1,03	[(W/m²K)]		
Floor :		1st Floor					
	1	2	3	4	5		6
s.n.	Structural element	Name	Brief name	Surface F m²	Coefficient of thermal transmittance U [(W/m²K)]		U*F [(W/K)]
1	Wall	EXTERIOR WALL (20cm)	W1	15,174	No. Leaf 1.1	1,859	28,214
		EXTERIOR WALL (10cm)	W2	115,720	No. Leaf 1.2	2,826	326,979
		Beam - brickwork - column	W3	38,123	No. Leaf 1.3	2,609	99,461
2	Opening	Single glass pane	F1	30,516	Table 1α	5,700	173,939
		Metal frame without thermal break	F2	12,259	Table 2α	7,000	85,816
			F3				0,000
3	$U_m(w,f)$			211,792			714,409
		$U_m(w,f) =$	**3,373**	<= 1,03 kcal/(m²hC)		**Needs improvement!**	

Thermal insulation of buildings in accordance with the R.En.E.B.							
Table 2			Subject	Apartments for Rent in Zakynthos			
			Address	Zakynthos			
			Owner	-			
No. Leaf 2.3			Studier	Dimitrios Chountalos			
			Altitude	7,9			
			Zone	A			
Calculation of thermal insulation of floor				**Attic**			
Proof :		$U_m(w,F)=(\Sigma(U_w{*}F_w)+\Sigma(U_f{*}F_f))/\Sigma(F_w+F_f) <=$		1,03	$[(W/m^2K)]$		
Floor :		Attic					
s.n.	1	2	3	4	5		6
	Structural element	NAME	BRIEF NAME	SURFACE F m^2	COEFFICIENT OF THERMAL TRANSMITTANCE U $[(W/m^2K)]$		U*F [(W/K)]
1	Wall	Exterior wall (20cm)	W1	13,355	No. Leaf 1.1	1,859	24,833
		Exterior wall (10cm)	W2	101,853	No. Leaf 1.2	2,826	287,794
		Beam - brickwork - column	W3	31,032	No. Leaf 1.3	2,609	80,962
2	Opening	Single glass pane	F1	18,014	Table 1α	5,700	102,679
		Metal frame without thermal break	F2	8,146	Table 2α	7,000	57,023
			F3				0,000
				172,400			553,291
3	$U_m(w,f)$	$U_m(w,f)$ =	**3,209**	<= 1,03 $kcal/(m^2hC)$	**Needs improvement!**		

Thermal insulation of buildings in accordance with the R.En.E.B.			
Table 3	Subject	Apartments for Rent in Zakynthos	
	Address	Zakynthos	
	Owner	-	
No. LEAF 3.1	Studier	Dimitrios Chountalos	
	Altitude	7,9	
	Zone	A	
Calculation of thermal insulation of the outer shell			
Proof :	$U_m=(U_W*F_W+U_F*F_F+0.80*U_D*F_D+U_D*F_D+U_G*F_G+U_{DL}*F_{DL}+0.50*U_{AB}*F_{AB})/(\Sigma(F_W+F_F+F_D+F_G+F_{DL}+F_{AB}) <= U_{m\ max}$		

s.n.	1	2	3	4	5 (3*4)	6	7 (5*6)
	Structural element	Brief name	Surface F m^2	Coefficient of thermal transmittance U [(W/m²K)]	U*F (W/K)	Coefficient	U*F (W/K)
Vertical external surfaces	No. Leaf 2.1		211,792	3,373	714,409	1,00	714,409
	No. Leaf 2.2		211,792	3,373	714,409	1,00	714,409
	No. Leaf 2.3		172,400	3,209	553,291	1,00	553,291
	No. Leaf 2.4		0,000	0,000	0,000	1,00	0,000
	No. Leaf 2.5		0,000	0,000	0,000	1,00	0,000
	No. Leaf 2.6		0,000	0,000	0,000	1,00	0,000
	No. Leaf 2.7		0,000	0,000	0,000	1,00	0,000
	No. Leaf 2.8		0,000	0,000	0,000	1,00	0,000
	No. Leaf 2.9		0,000	0,000	0,000	1,00	0,000
	No. Leaf 2.10		0,000	0,000	0,000	1,00	0,000

Horizontal surfaces	Ceiling, doma, roof	D1	187,219	2,703	505,998	1,00	505,998
	Ceiling under roof Which is not thermally insulated	D2	0,000	0,000	0,000	0,80	0,000
	Floor over an enclosed non heated space (ceiling of basement)	G1	0,000	0,000	0,000	0,50	0,000
	Floor up on the ground	G2	177,030	3,247	574,812	0,50	287,406
	Floor over open space (pilotis, semi - outdoor space)	DL	0,000	0,000	0,000	1,00	0,000
	Departments which bordering with low temperature spaces	AB1	0,000	0,000	0,000	0,50	0,000
		AB2	0,000	0,000	0,000	0,50	0,000
			960,234				2775,512

$U_m = \dfrac{2775,512}{960,234}$ **= 2,890** $W/(m^2K)$ **needs improvement!**

$U_{m,max} =$ **1,030** $W/(m^2K)$

$U_m < U_{m,max}$

APPENDIX III

Table 1a÷d: Detailed calculation of Correction Factor F for all months for 20 years of operation of the PV System

Table 1a: Stable parameters during the 20 years of operation of the PV System. I, I_T, T_a, λ, T_{pv}, dP_m/P_m, Π_{temp}, n_{cables} & $n_{inverter}$ - monthly average values

Month	I [W/m^2]	I_T [W/m^2]	T_a [^oC]	λ	T_{pv} [^oC]	dP_m/P_m [%]	Π_{temp}	n_{cables}	$n_{inverter}$
Jan	157	187	12,5	0,03	18,10	3,1063	1,031063	0,98	0,985
Feb	240	278	12,2	0,03	20,54	2,0077	1,020077	0,98	0,985
Mar	294	323	13,9	0,03	23,58	0,6407	1,006407	0,98	0,985
Apr	351	360	16,0	0,03	26,80	-0,8112	0,991888	0,98	0,985
May	462	450	19,7	0,03	33,21	-3,6923	0,963077	0,98	0,985
Jun	370	348	23,6	0,03	34,03	-4,0622	0,959378	0,98	0,985
Jul	439	418	26,2	0,03	38,74	-6,1829	0,938171	0,98	0,985
Aug	397	404	26,9	0,03	39,01	-6,3037	0,936963	0,98	0,985
Sep	318	351	24,2	0,03	34,72	-4,3741	0,956259	0,98	0,985
Oct	228	273	20,9	0,03	29,08	-1,8338	0,981662	0,98	0,985
Nov	171	205	17,7	0,03	23,84	0,5198	1,005198	0,98	0,985
Dec	134	155	14,3	0,03	18,96	2,7199	1,027199	0,98	0,985

Table 1b: Efficiency due to ageing of the photovoltaics, $\eta_{pv\text{-}ageing}$ [%]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st ÷ 20th year	99÷80	99÷80	99÷80	99÷80	99÷80	99÷80	99÷80	99÷80	99÷80	99÷80	99÷80	99÷80

Table 1c: Mean monthly values of the overall efficiency of the PV System, Π_i

Month	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year	18th year	19th year	20th year	Average
Jan	0,9853	0,9754	0,9654	0,9555	0,9455	0,9356	0,9256	0,9157	0,9057	0,8958	0,8858	0,8759	0,8659	0,8559	0,8460	0,8360	0,8261	0,8161	0,8062	0,7962	0,8908
Feb	0,9748	0,9650	0,9551	0,9453	0,9354	0,9256	0,9158	0,9059	0,8961	0,8862	0,8764	0,8665	0,8567	0,8468	0,8370	0,8271	0,8173	0,8074	0,7976	0,7877	0,8813
Mar	0,9618	0,9521	0,9423	0,9326	0,9229	0,9132	0,9035	0,8938	0,8841	0,8743	0,8646	0,8549	0,8452	0,8355	0,8258	0,8160	0,8063	0,7966	0,7869	0,7772	0,8695
Apr	0,9479	0,9383	0,9287	0,9192	0,9096	0,9000	0,8904	0,8809	0,8713	0,8617	0,8521	0,8426	0,8330	0,8234	0,8138	0,8043	0,7947	0,7851	0,7756	0,7660	0,8569
May	0,9204	0,9111	0,9018	0,8925	0,8832	0,8739	0,8646	0,8553	0,8460	0,8367	0,8274	0,8181	0,8088	0,7995	0,7902	0,7809	0,7716	0,7623	0,7530	0,7437	0,8320
Jun	0,9168	0,9076	0,8983	0,8890	0,8798	0,8705	0,8613	0,8520	0,8427	0,8335	0,8242	0,8150	0,8057	0,7964	0,7872	0,7779	0,7687	0,7594	0,7501	0,7409	0,8288
Jul	0,8966	0,8875	0,8784	0,8694	0,8603	0,8513	0,8422	0,8332	0,8241	0,8151	0,8060	0,7969	0,7879	0,7788	0,7698	0,7607	0,7517	0,7426	0,7335	0,7245	0,8105
Aug	0,8954	0,8864	0,8773	0,8683	0,8592	0,8502	0,8411	0,8321	0,8231	0,8140	0,8050	0,7959	0,7869	0,7778	0,7688	0,7597	0,7507	0,7416	0,7326	0,7236	0,8095
Sep	0,9138	0,9046	0,8954	0,8862	0,8769	0,8677	0,8585	0,8492	0,8400	0,8308	0,8215	0,8123	0,8031	0,7938	0,7846	0,7754	0,7662	0,7569	0,7477	0,7385	0,8262
Oct	0,9381	0,9286	0,9192	0,9097	0,9002	0,8907	0,8813	0,8718	0,8623	0,8528	0,8434	0,8339	0,8244	0,8149	0,8055	0,7960	0,7865	0,7770	0,7676	0,7581	0,8481
Nov	0,9606	0,9509	0,9412	0,9315	0,9218	0,9121	0,9024	0,8927	0,8830	0,8733	0,8636	0,8539	0,8442	0,8345	0,8248	0,8151	0,8054	0,7957	0,7860	0,7763	0,8684
Dec	0,9816	0,9717	0,9618	0,9519	0,9420	0,9321	0,9221	0,9122	0,9023	0,8924	0,8825	0,8726	0,8627	0,8527	0,8428	0,8329	0,8230	0,8131	0,8032	0,7932	0,8874
Annual	0,9411	0,9316	0,9221	0,9126	0,9031	0,8936	0,8841	0,8746	0,8651	0,8555	0,8460	0,8365	0,8270	0,8175	0,8080	0,7985	0,7890	0,7795	0,7700	0,7605	0,8508

Table 1d: Mean monthly values of the Correction Factor F

Month	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year	18th year	19th year	20th year	Average
Jan	1,01	1,03	1,04	1,05	1,06	1,07	1,08	1,09	1,10	1,12	1,13	1,14	1,15	1,17	1,18	1,20	1,21	1,23	1,24	1,26	1,13
Feb	1,03	1,04	1,05	1,06	1,07	1,08	1,09	1,10	1,12	1,13	1,14	1,15	1,17	1,18	1,19	1,21	1,22	1,24	1,25	1,27	1,14
Mar	1,04	1,05	1,06	1,07	1,08	1,10	1,11	1,12	1,13	1,14	1,16	1,17	1,18	1,20	1,21	1,23	1,24	1,26	1,27	1,29	1,15
Apr	1,05	1,07	1,08	1,09	1,10	1,11	1,12	1,14	1,15	1,16	1,17	1,19	1,20	1,21	1,23	1,24	1,26	1,27	1,29	1,31	1,17
May	1,09	1,10	1,11	1,12	1,13	1,14	1,16	1,17	1,18	1,20	1,21	1,22	1,24	1,25	1,27	1,28	1,30	1,31	1,33	1,34	1,21
Jun	1,09	1,10	1,11	1,12	1,14	1,15	1,16	1,17	1,19	1,20	1,21	1,23	1,24	1,26	1,27	1,29	1,30	1,32	1,33	1,35	1,21
Jul	1,12	1,13	1,14	1,15	1,16	1,17	1,19	1,20	1,21	1,23	1,24	1,25	1,27	1,28	1,30	1,31	1,33	1,35	1,36	1,38	1,24
Aug	1,12	1,13	1,14	1,15	1,16	1,18	1,19	1,20	1,21	1,23	1,24	1,26	1,27	1,29	1,30	1,32	1,33	1,35	1,36	1,38	1,24
Sep	1,09	1,11	1,12	1,13	1,14	1,15	1,16	1,18	1,19	1,20	1,22	1,23	1,25	1,26	1,27	1,29	1,31	1,32	1,34	1,35	1,22
Oct	1,07	1,08	1,09	1,10	1,11	1,12	1,13	1,15	1,16	1,17	1,19	1,20	1,21	1,23	1,24	1,26	1,27	1,29	1,30	1,32	1,18
Nov	1,04	1,05	1,06	1,07	1,08	1,10	1,11	1,12	1,13	1,15	1,16	1,17	1,18	1,20	1,21	1,23	1,24	1,26	1,27	1,29	1,16
Dec	1,02	1,03	1,04	1,05	1,06	1,07	1,08	1,10	1,11	1,12	1,13	1,15	1,16	1,17	1,19	1,20	1,22	1,23	1,25	1,26	1,13
Annual	1,06	1,07	1,09	1,10	1,11	1,12	1,13	1,14	1,16	1,17	1,18	1,20	1,21	1,22	1,24	1,25	1,27	1,28	1,30	1,32	1,18

Table 2a÷l: PivotTables of the parameters of I, R, Q_L, E_{PV}, DE, $E_{PV,Real}$ and the ratios of $E_{PV,Real}/E_{PV}$, DE/Q_L

Table 2a: Mean monthly daily values of solar radiation from daily data of 20 years from the database SODA (1985-2004), H [KWh/m^2-day] & mean monthly values of solar radiation from daily data of 20 years from the database SODA (1985-2004), H [KWh/m^2-month]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Average
H [KWh/m^2-day] 1st ÷ 20st year	1,86	2,64	3,84	4,91	6,18	7,23	7,26	6,46	4,80	3,42	2,09	1,49	-	4,35
H [KWh/m^2-month] 1st ÷ 20st year	58	77	119	147	192	217	225	200	144	106	63	46	1594	133

I_{Total} = 1594 · 20 = 31880 KWh/20years & Average I_{Total} = 31880 ÷ 12 = 2657 KWh/month-20years

Table 2b: Mean monthly values of coefficient R from daily data of 20 years from the database SODA (1985-2004)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1st ÷ 20st year	1,19013	1,15948	1,09884	1,02674	0,97359	0,93826	0,95234	1,01610	1,10239	1,19678	1,19460	1,15879	1,08379

Table 2c: Mean monthly values of non-critical loads, Q_L [KWh/month]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Average
1st ÷ 20st year	3130	4150	3396	2046	1746	3330	3995	3995	1896	2546	3663	3027	36920	3077

$Q_{L,Total}$ = 36920 · 20 =738400 KWh/20years & Monthly average of $Q_{L,Total}$ =738400 ÷ 12 = 61533 KWh/month-20years

Table 2d: Mean monthly values of the energy produced by the PV System with the same peak power (P_m), E_{PV} [KWh/month]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Average
1st - 20st year	1791	2327	3398	3927	4848	5289	5573	5284	4119	3294	1958	1403	43210	3601

$E_{PV,Total}$ = 43210 · 20 = 864197KWh/20years & Monthly average of $E_{PV,Total}$ = 864197 ÷ 12 = 72016KWh/month-20years

Table 2e: Mean monthly values of the remaining amount of energy delivered by the PV System, after its consumption by the load, DE [KWh/month]

Month	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year	18th year	19th year	20th year	Total	Average
Jan	-1371	-1434	-1465	-1496	-1528	-1559	-1590	-1622	-1653	-1716	-1747	-1778	-1810	-1872	-1904	-1966	-1997	-2060	-2091	-2154	-34814	-1741
Feb	-2094	-2137	-2180	-2223	-2266	-2309	-2352	-2395	-2481	-2523	-2566	-2609	-2695	-2738	-2781	-2867	-2910	-2996	-3038	-3124	-51284	-2564
Mar	-149	-183	-217	-251	-285	-353	-388	-422	-456	-490	-558	-592	-626	-694	-729	-797	-831	-899	-933	-1001	-10854	-543
Apr	1785	1744	1724	1703	1683	1662	1642	1601	1581	1560	1540	1499	1479	1458	1418	1397	1356	1336	1295	1254	30719	1536
May	2956	2939	2921	2904	2887	2869	2834	2817	2800	2765	2748	2730	2696	2678	2643	2626	2591	2574	2539	2522	55040	2752
Jun	1659	1626	1592	1559	1492	1459	1426	1392	1326	1293	1259	1193	1159	1093	1059	993	960	893	860	793	25086	1254
Jul	1094	1054	1014	974	934	894	814	774	734	654	614	574	494	454	374	334	254	174	134	54	12403	620
Aug	805	765	725	685	645	565	525	485	445	365	325	245	205	125	85	5	-35	-115	-155	-235	6463	323
Sep	2059	2021	2002	1983	1964	1946	1927	1889	1870	1851	1813	1794	1757	1738	1719	1681	1643	1624	1586	1568	36435	1822
Oct	574	549	523	498	472	447	422	371	345	320	269	244	218	167	142	91	66	15	-11	-61	5660	283
Nov	-1848	-1885	-1922	-1958	-1995	-2068	-2105	-2141	-2178	-2251	-2288	-2324	-2361	-2434	-2471	-2544	-2580	-2654	-2690	-2763	-45458	-2273
Dec	-1696	-1726	-1756	-1787	-1817	-1847	-1878	-1939	-1969	-1999	-2030	-2090	-2121	-2151	-2212	-2242	-2303	-2334	-2394	-2425	-40716	-2036
Annual	3773	3332	2962	2591	2187	1706	1278	812	365	-171	-620	-1115	-1605	-2176	-2655	-3288	-3786	-4440	-4898	-5573	-11322	-566
Average	314	278	247	216	182	142	106	68	30	-14	-52	-93	-134	-181	-221	-274	-315	-370	-408	-464	-943	-47

Table 2f: Mean monthly values of the real energy delivered by the PV System after its degradation, $E_{PV,Real}$ [KWh/month]

Month	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year	18th year	19th year	20th year	Total	Average
Jan	1759	1696	1665	1633	1602	1571	1539	1508	1477	1414	1383	1351	1320	1258	1226	1164	1132	1070	1038	976	27781	1389
Feb	2055	2013	1970	1927	1884	1841	1798	1755	1669	1626	1583	1540	1455	1412	1369	1283	1240	1154	1111	1025	31709	1585
Mar	3247	3213	3179	3145	3111	3043	3009	2975	2941	2906	2838	2804	2770	2702	2668	2600	2565	2497	2463	2395	57072	2854
Apr	3831	3790	3770	3749	3729	3708	3688	3647	3627	3606	3586	3545	3525	3504	3464	3443	3402	3382	3341	3300	71637	3582
May	4702	4684	4667	4650	4632	4615	4580	4563	4546	4511	4494	4476	4441	4424	4389	4372	4337	4320	4285	4268	89957	4498
Jun	4989	4956	4923	4889	4823	4789	4756	4723	4656	4623	4590	4523	4490	4423	4390	4323	4290	4223	4190	4123	91692	4585
Jul	5089	5049	5009	4969	4929	4889	4809	4769	4729	4649	4609	4569	4489	4449	4369	4329	4249	4169	4129	4049	92303	4615
Aug	4800	4760	4720	4680	4640	4560	4520	4480	4440	4360	4320	4240	4200	4120	4080	4000	3960	3880	3840	3760	86363	4318
Sep	3955	3917	3898	3879	3861	3842	3823	3785	3766	3747	3709	3690	3653	3634	3615	3577	3539	3520	3483	3464	74358	3718
Oct	3120	3095	3069	3044	3018	2993	2968	2917	2891	2866	2815	2790	2764	2713	2688	2637	2612	2561	2535	2485	56579	2829
Nov	1814	1778	1741	1705	1668	1595	1558	1522	1485	1412	1375	1339	1302	1229	1192	1119	1082	1009	973	899	27798	1390
Dec	1331	1301	1270	1240	1210	1179	1149	1088	1058	1027	997	936	906	875	815	784	724	693	632	602	19819	991
Annual	40693	40252	39881	39510	39106	38625	38197	37731	37284	36748	36299	35805	35315	34743	34265	33631	33134	32479	32022	31347	727068	36353
Average	3391	3354	3323	3293	3259	3219	3183	3144	3107	3062	3025	2984	2943	2895	2855	2803	2761	2707	2668	2612	60589	3029

Table 2g: Mean monthly values of non-critical loads, Q_L [€/month]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Average
1st ÷ 20st year	720	954	781	471	402	766	919	919	436	586	842	696	8491	708

$Q_{L,Total}$ = 169830 €/20years & Monthly average of $Q_{L,Total}$ = 14152 €/month-20years

Table 2h: Mean monthly values of the energy produced by the PV System with the same peak power (P_m), E_{PV} [€/month]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Average
1st ÷ 20st year	412	535	781	903	1115	1216	1282	1215	947	758	450	323	9938	828

$E_{PV,Total}$ = 168765 €/20years & Average $E_{PV,Total}$ = 16564 €/month-20years

Table 2i: Mean monthly values of the remaining amount of energy delivered by the PV System, after its consumption by the load, DE [€/month]

Month	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year	18th year	19th year	20th year	Total	Average
Jan	-315	-330	-337	-344	-351	-359	-366	-373	-380	-395	-402	-409	-416	-431	-438	-452	-459	-474	-481	-495	-8007	-400
Feb	-482	-492	-501	-511	-521	-531	-541	-551	-571	-580	-590	-600	-620	-630	-640	-659	-669	-689	-699	-719	-11795	-590
Mar	-34	-42	-50	-58	-66	-81	-89	-97	-105	-113	-128	-136	-144	-160	-168	-183	-191	-207	-215	-230	-2496	-125
Apr	411	401	396	392	387	382	378	368	364	359	354	345	340	335	326	321	312	307	298	289	7065	353
May	680	676	672	668	664	660	652	648	644	636	632	628	620	616	608	604	596	592	584	580	12659	633
Jun	382	374	366	359	343	336	328	320	305	297	290	274	267	251	244	228	221	205	198	182	5770	288
Jul	252	242	233	224	215	206	187	178	169	150	141	132	114	104	86	77	58	40	31	12	2853	143
Aug	185	176	167	158	148	130	121	112	102	84	75	56	47	29	20	1	-8	-26	-36	-54	1486	74
Sep	474	465	461	456	452	447	443	434	430	426	417	413	404	400	395	387	378	374	365	361	8380	419
Oct	132	126	120	114	109	103	97	85	79	74	62	56	50	38	33	21	15	3	-2	-14	1302	65
Nov	-425	-434	-442	-450	-459	-476	-484	-492	-501	-518	-526	-535	-543	-560	-568	-585	-593	-610	-619	-636	-10455	-523
Dec	-390	-397	-404	-411	-418	-425	-432	-446	-453	-460	-467	-481	-488	-495	-509	-516	-530	-537	-551	-558	-9365	-468
Annual	868	766	681	596	503	392	294	187	84	-39	-143	-256	-369	-501	-611	-756	-871	-1021	-1127	-1282	-2604	-130
Average	72	64	57	50	42	33	24	16	7	-3	-12	-21	-31	-42	-51	-63	-73	-85	-94	-107	-217	-11

Table 2j: Mean monthly values of the real energy delivered by the PV System after its degradation, $E_{PV,Real}$ [€/month].

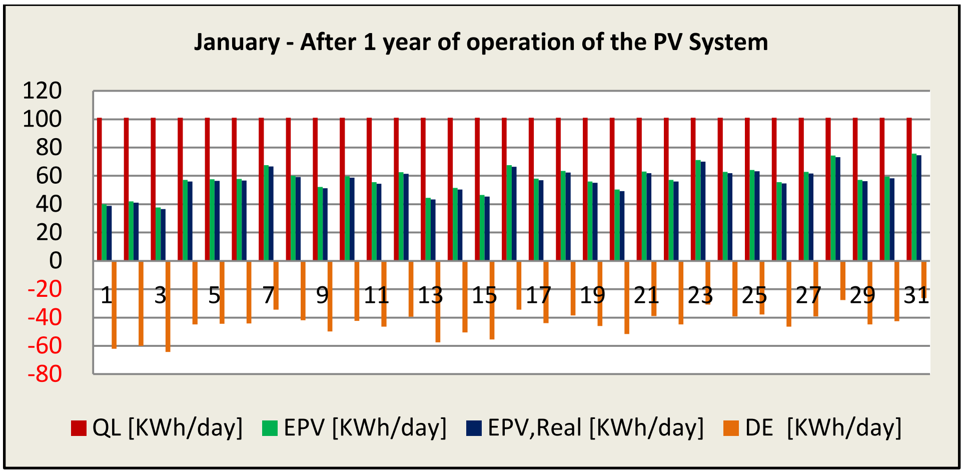
Month	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year	18th year	19th year	20th year	Total	Average
Jan	404	390	383	376	368	361	354	347	340	325	318	311	304	289	282	268	260	246	239	224	6390	319
Feb	473	463	453	443	433	423	414	404	384	374	364	354	335	325	315	295	285	265	256	236	7293	365
Mar	747	739	731	723	716	700	692	684	676	668	653	645	637	621	614	598	590	574	567	551	13127	656
Apr	881	872	867	862	858	853	848	839	834	829	825	815	811	806	797	792	783	778	768	759	16477	824
May	1081	1077	1073	1069	1065	1061	1053	1049	1045	1038	1034	1030	1022	1018	1010	1006	998	994	986	982	20690	1035
Jun	1148	1140	1132	1125	1109	1102	1094	1086	1071	1063	1056	1040	1033	1017	1010	994	987	971	964	948	21089	1054
Jul	1170	1161	1152	1143	1134	1124	1106	1097	1088	1069	1060	1051	1033	1023	1005	996	977	959	950	931	21230	1061
Aug	1104	1095	1086	1076	1067	1049	1040	1030	1021	1003	994	975	966	948	938	920	911	892	883	865	19863	993
Sep	910	901	897	892	888	884	879	871	866	862	853	849	840	836	831	823	814	810	801	797	17102	855
Oct	718	712	706	700	694	688	683	671	665	659	647	642	636	624	618	607	601	589	583	571	13013	651
Nov	417	409	400	392	384	367	358	350	342	325	316	308	299	283	274	257	249	232	224	207	6394	320
Dec	306	299	292	285	278	271	264	250	243	236	229	215	208	201	187	180	166	159	145	138	4558	228
Annual	9359	9258	9173	9087	8994	8884	8785	8678	8575	8452	8349	8235	8122	7991	7881	7735	7621	7470	7365	7210	167226	8361
Average	780	771	764	757	750	740	732	723	715	704	696	686	677	666	657	645	635	623	614	601	13935	697

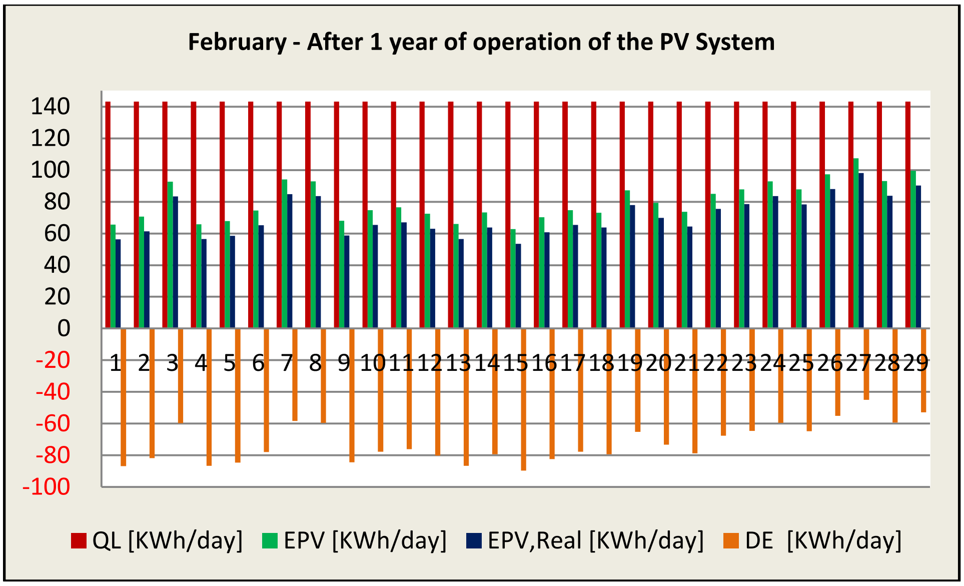
Table 2k: Mean monthly values of the percentage of the real energy delivered by the PV System after its degradation, as to the maximum energy that could be delivered by the PV System, $E_{PV,Real}/E_{PV}$ [%]

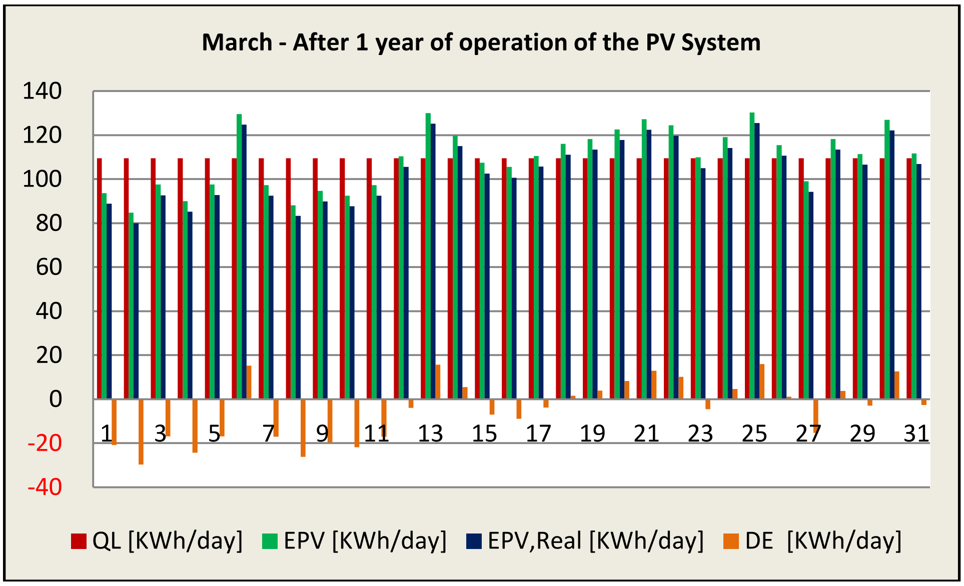
Month	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year	18th year	19th year	20th year	Average
Jan	98,2	94,7	92,9	91,2	89,4	87,7	85,9	84,2	82,5	79,0	77,2	75,5	73,7	70,2	68,5	65,0	63,2	59,7	58,0	54,5	77,6
Feb	88,3	86,5	84,7	82,8	81,0	79,1	77,3	75,4	71,7	69,9	68,1	66,2	62,5	60,7	58,8	55,1	53,3	49,6	47,8	44,1	68,1
Mar	95,6	94,6	93,6	92,6	91,6	89,6	88,6	87,6	86,5	85,5	83,5	82,5	81,5	79,5	78,5	76,5	75,5	73,5	72,5	70,5	84,0
Apr	97,6	96,5	96,0	95,5	95,0	94,4	93,9	92,9	92,4	91,8	91,3	90,3	89,8	89,2	88,2	87,7	86,6	86,1	85,1	84,0	91,2
May	97,0	96,6	96,3	95,9	95,5	95,2	94,5	94,1	93,8	93,0	92,7	92,3	91,6	91,3	90,5	90,2	89,5	89,1	88,4	88,0	92,8
Jun	94,3	93,7	93,1	92,4	91,2	90,6	89,9	89,3	88,0	87,4	86,8	85,5	84,9	83,6	83,0	81,7	81,1	79,9	79,2	78,0	86,7
Jul	91,3	90,6	89,9	89,2	88,4	87,7	86,3	85,6	84,9	83,4	82,7	82,0	80,6	79,8	78,4	77,7	76,2	74,8	74,1	72,7	82,8
Aug	90,8	90,1	89,3	88,6	87,8	86,3	85,5	84,8	84,0	82,5	81,8	80,2	79,5	78,0	77,2	75,7	74,9	73,4	72,7	71,2	81,7
Sep	96,0	95,1	94,6	94,2	93,7	93,3	92,8	91,9	91,4	91,0	90,1	89,6	88,7	88,2	87,8	86,8	85,9	85,5	84,5	84,1	90,3
Oct	94,7	93,9	93,2	92,4	91,6	90,9	90,1	88,5	87,8	87,0	85,5	84,7	83,9	82,4	81,6	80,1	79,3	77,7	77,0	75,4	85,9
Nov	92,7	90,8	88,9	87,1	85,2	81,5	79,6	77,7	75,8	72,1	70,2	68,4	66,5	62,8	60,9	57,2	55,3	51,5	49,7	45,9	71,0
Dec	94,9	92,7	90,5	88,4	86,2	84,0	81,9	77,5	75,4	73,2	71,1	66,7	64,6	62,4	58,1	55,9	51,6	49,4	45,1	42,9	70,6
Annual	94,2	93,2	92,3	91,4	90,5	89,4	88,4	87,3	86,3	85,0	84,0	82,9	81,7	80,4	79,3	77,8	76,7	75,2	74,1	72,5	84,1
Degradation	5,8	1,0	0,9	0,9	0,9	1,1	1,0	1,1	1,0	1,2	1,0	1,1	1,1	1,3	1,1	1,5	1,2	1,5	1,1	1,6	1,1

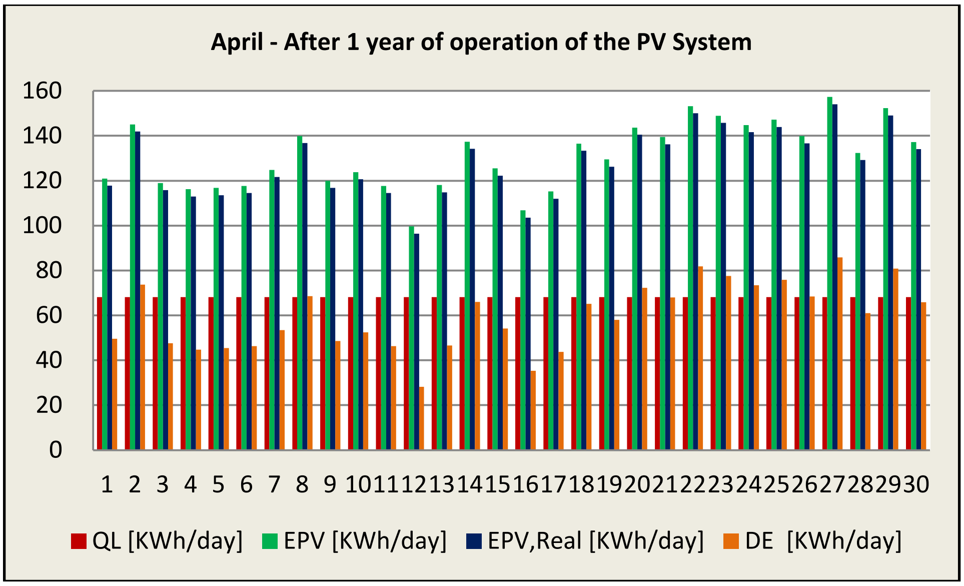
Table 2l: Mean monthly values of the percentage of the excess or lack of electrical energy in relation to the electrical needs of the apartments, DE/Q_L [%]

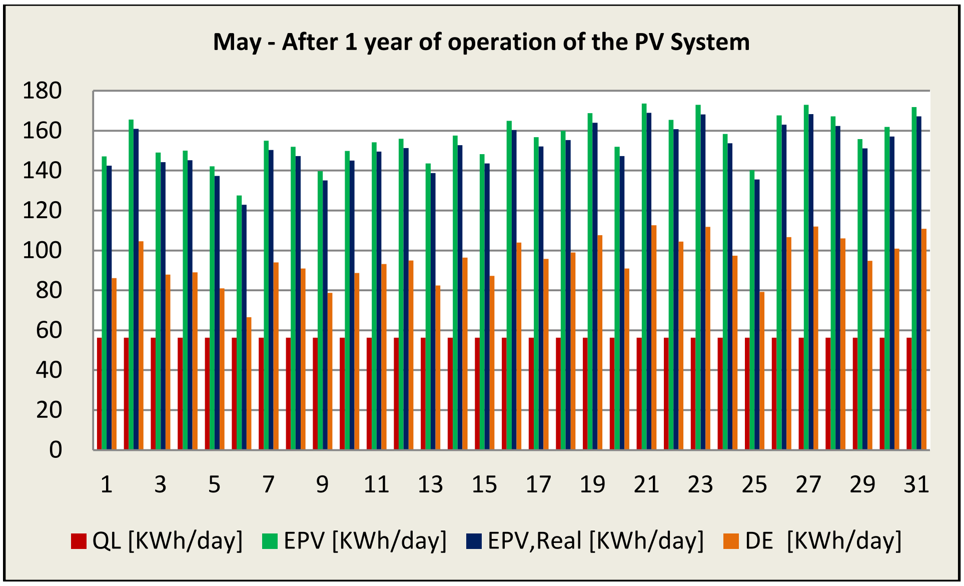
Month	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year	18th year	19th year	20th year	Average
Jan	-43,8	-45,8	-46,8	-47,8	-48,8	-49,8	-50,8	-51,8	-52,8	-54,8	-55,8	-56,8	-57,8	-59,8	-60,8	-62,8	-63,8	-65,8	-66,8	-68,8	-55,6
Feb	-50,5	-51,5	-52,5	-53,6	-54,6	-55,6	-56,7	-57,7	-59,8	-60,8	-61,8	-62,9	-64,9	-66,0	-67,0	-69,1	-70,1	-72,2	-73,2	-75,3	-61,8
Mar	-4,4	-5,4	-6,4	-7,4	-8,4	-10,4	-11,4	-12,4	-13,4	-14,4	-16,4	-17,4	-18,4	-20,4	-21,5	-23,5	-24,5	-26,5	-27,5	-29,5	-16,0
Apr	87,2	85,2	84,2	83,3	82,3	81,3	80,3	78,3	77,3	76,3	75,3	73,3	72,3	71,3	69,3	68,3	66,3	65,3	63,3	61,3	75,1
May	169,3	168,3	167,3	166,3	165,3	164,3	162,4	161,4	160,4	158,4	157,4	156,4	154,4	153,4	151,4	150,4	148,4	147,4	145,4	144,5	157,6
Jun	49,8	48,8	47,8	46,8	44,8	43,8	42,8	41,8	39,8	38,8	37,8	35,8	34,8	32,8	31,8	29,8	28,8	26,8	25,8	23,8	37,7
Jul	27,4	26,4	25,4	24,4	23,4	22,4	20,4	19,4	18,4	16,4	15,4	14,4	12,4	11,4	9,4	8,4	6,4	4,4	3,4	1,4	15,5
Aug	20,2	19,1	18,1	17,1	16,1	14,1	13,1	12,1	11,1	9,1	8,1	6,1	5,1	3,1	2,1	0,1	-0,9	-2,9	-3,9	-5,9	8,1
Sep	108,6	106,6	105,6	104,6	103,6	102,6	101,6	99,6	98,6	97,6	95,6	94,6	92,6	91,6	90,6	88,6	86,7	85,7	83,7	82,7	96,1
Oct	22,5	21,5	20,6	19,6	18,6	17,6	16,6	14,6	13,6	12,6	10,6	9,6	8,6	6,6	5,6	3,6	2,6	0,6	-0,4	-2,4	11,1
Nov	-50,5	-51,5	-52,5	-53,5	-54,5	-56,5	-57,5	-58,5	-59,5	-61,5	-62,5	-63,5	-64,5	-66,5	-67,4	-69,4	-70,4	-72,4	-73,4	-75,4	-62,1
Dec	-56,0	-57,0	-58,0	-59,0	-60,0	-61,0	-62,0	-64,0	-65,1	-66,1	-67,1	-69,1	-70,1	-71,1	-73,1	-74,1	-76,1	-77,1	-79,1	-80,1	-67,3
Annual	10,2	9,0	8,0	7,0	5,9	4,6	3,5	2,2	1,0	-0,5	-1,7	-3,0	-4,3	-5,9	-7,2	-8,9	-10,3	-12,0	-13,3	-15,1	-1,5
Degradation	-	1,2	1,0	1,0	1,1	1,3	1,2	1,3	1,2	1,5	1,2	1,3	1,3	1,5	1,3	1,7	1,3	1,8	1,2	1,8	1,3

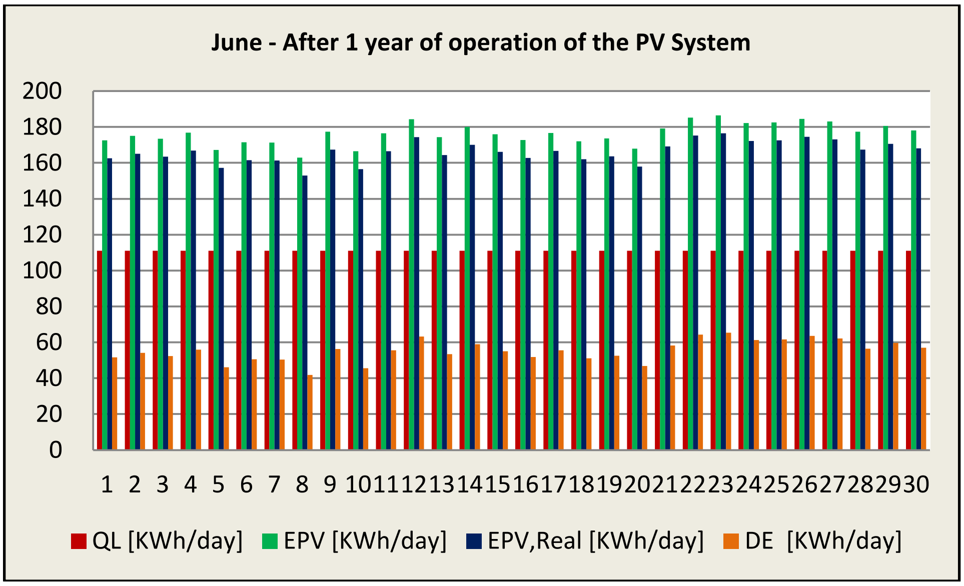

January - After 1 year of operation of the PV System
120
100
80
60
40
20
0
-20
-40
-60
-80
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

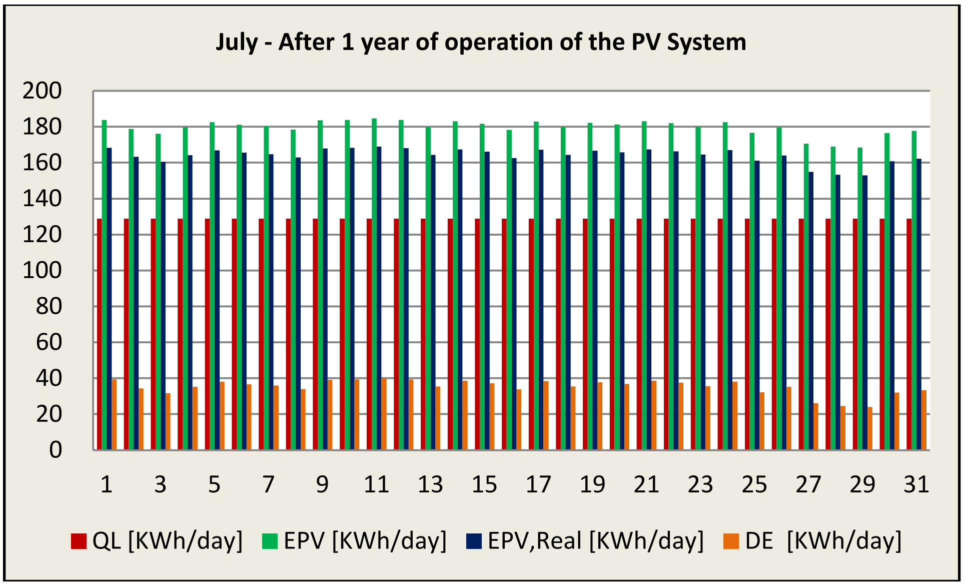

February - After 1 year of operation of the PV System
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

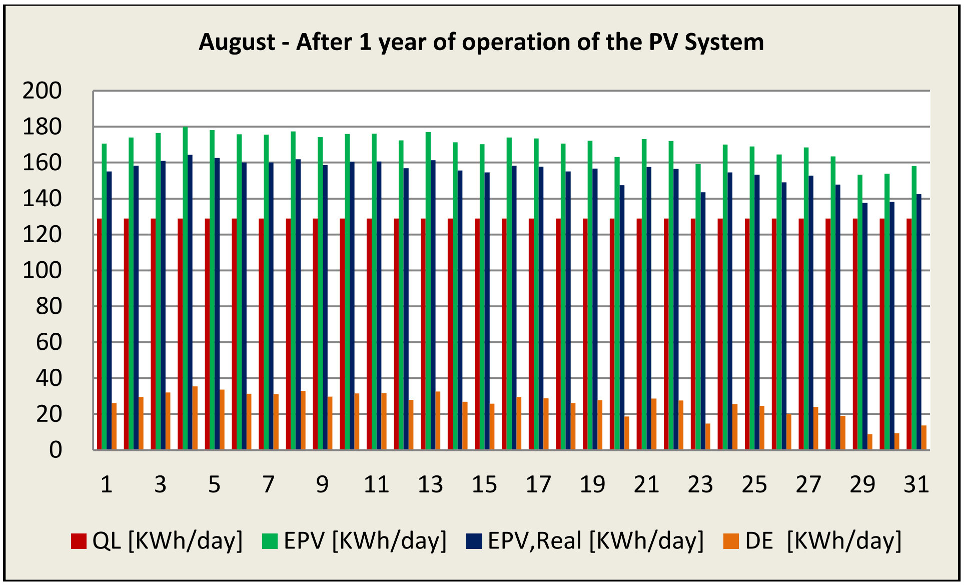

March - After 1 year of operation of the PV System
140
120
100
80
60
40
20
0
-20
-40
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

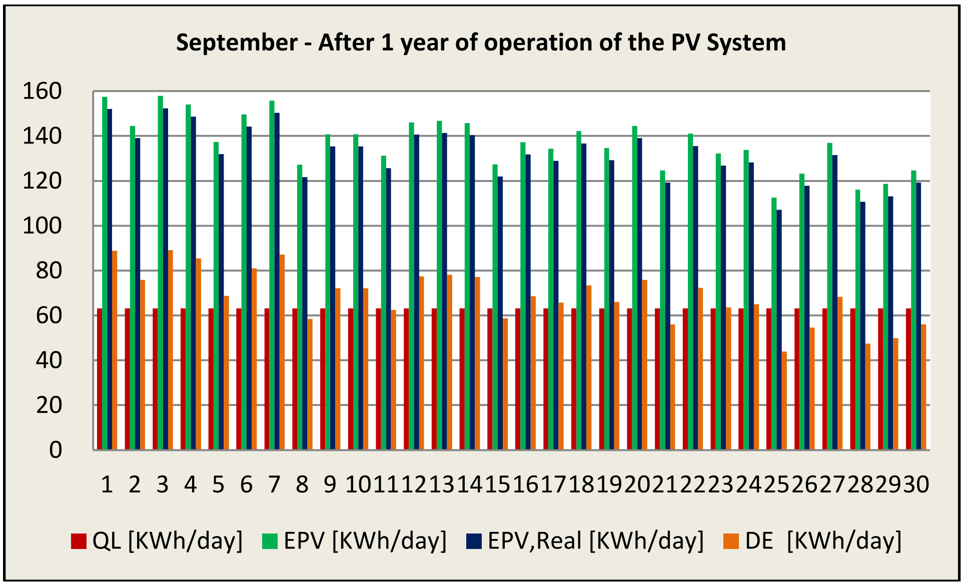

April - After 1 year of operation of the PV System
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 101112131415161718192021222324252627282930
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

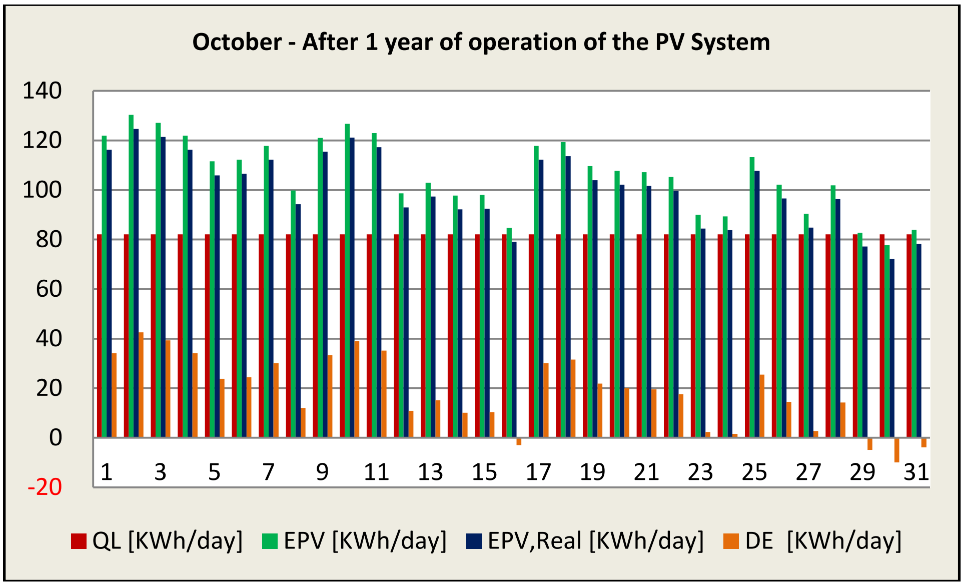

May - After 1 year of operation of the PV System
180
160
140
120
100
80
60
40
20
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

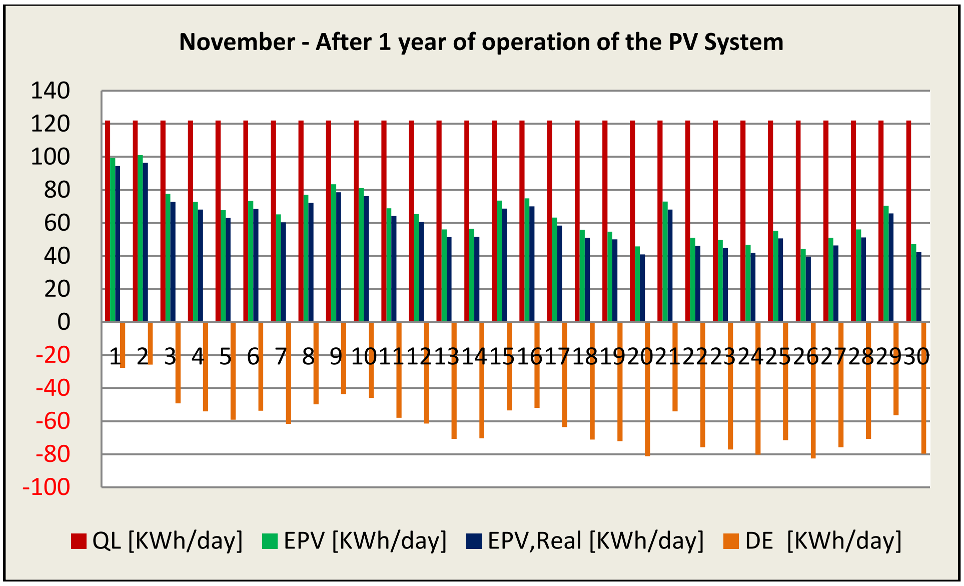

June - After 1 year of operation of the PV System
200
180
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 101112131415161718192021222324252627282930
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

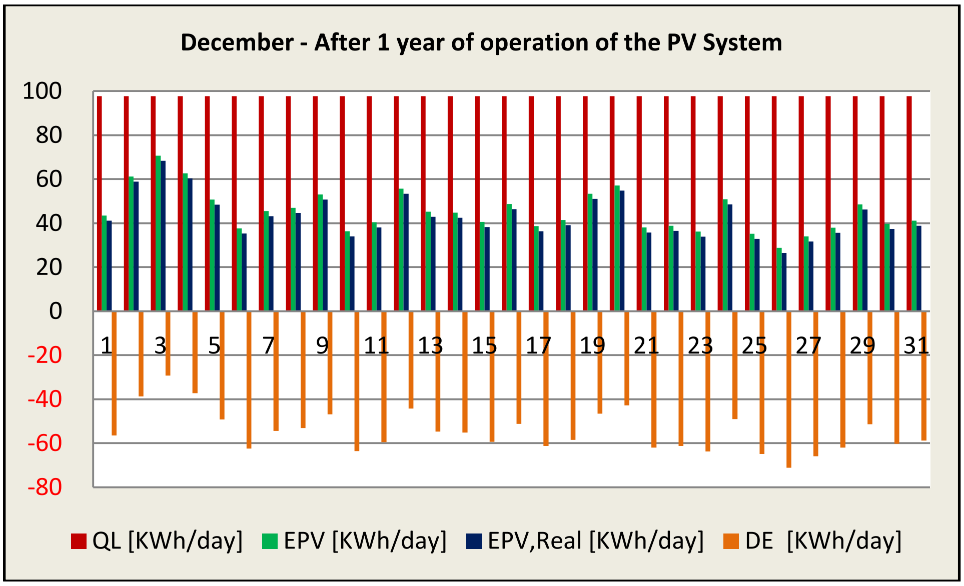

July - After 1 year of operation of the PV System
200
180
160
140
120
100
80
60
40
20
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

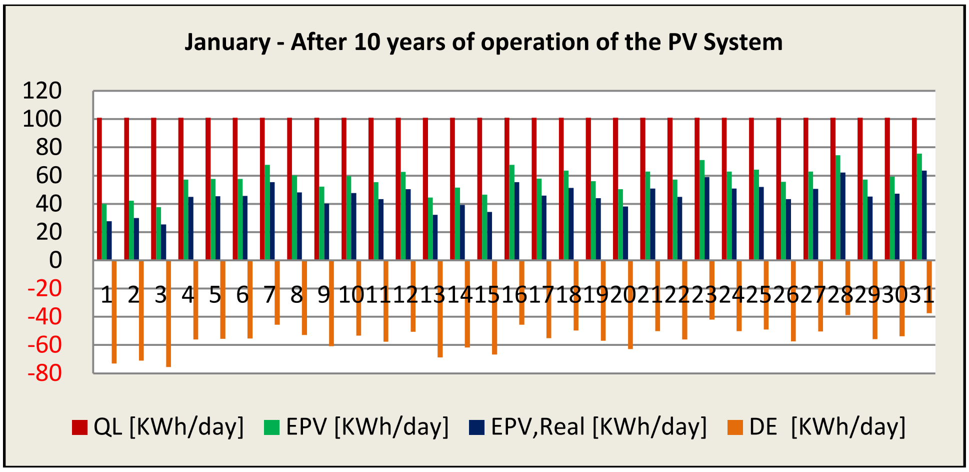

August - After 1 year of operation of the PV System
200
180
160
140
120
100
80
60
40
20
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

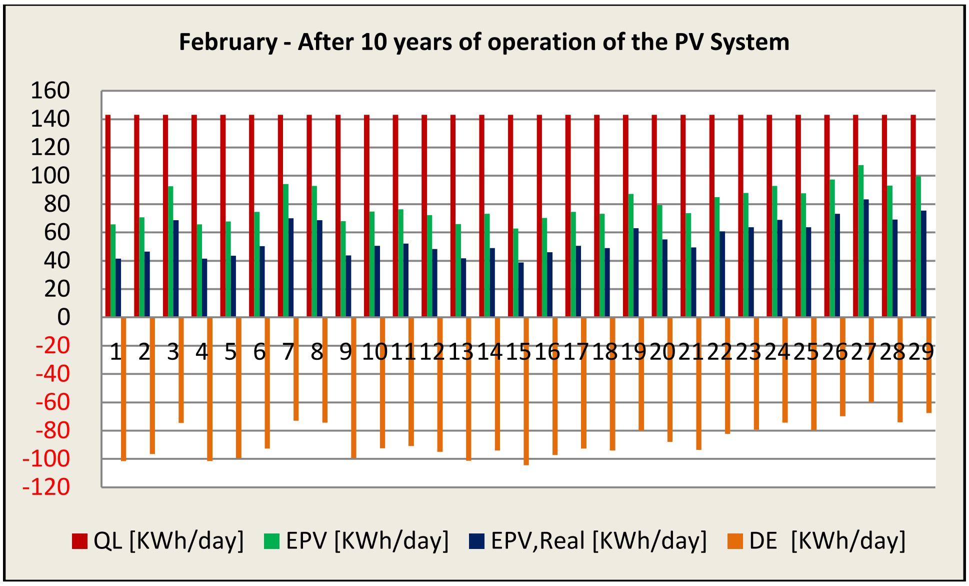

September - After 1 year of operation of the PV System
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 101112131415161718192021222324252627282930
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

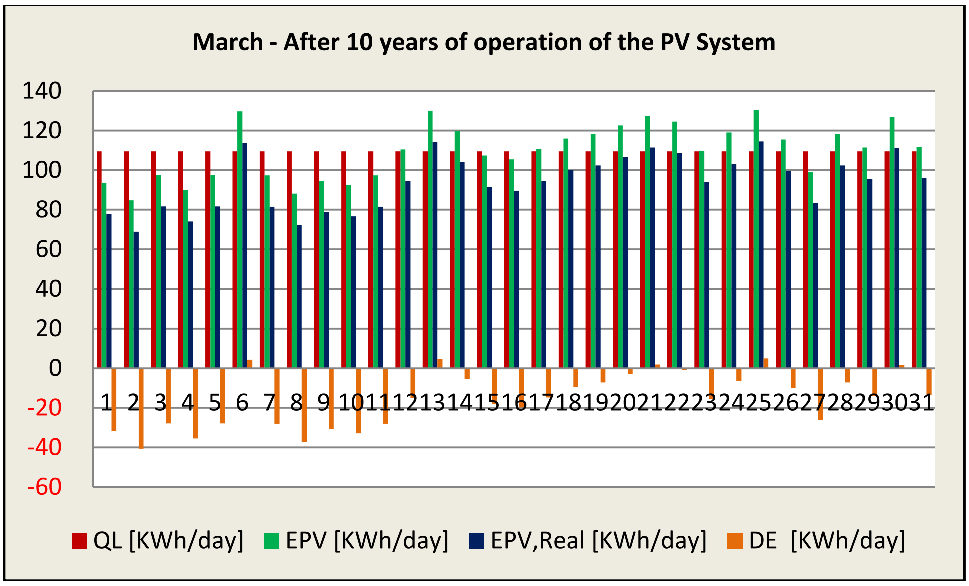

October - After 1 year of operation of the PV System
140
120
100
80
60
40
20
0
-20
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

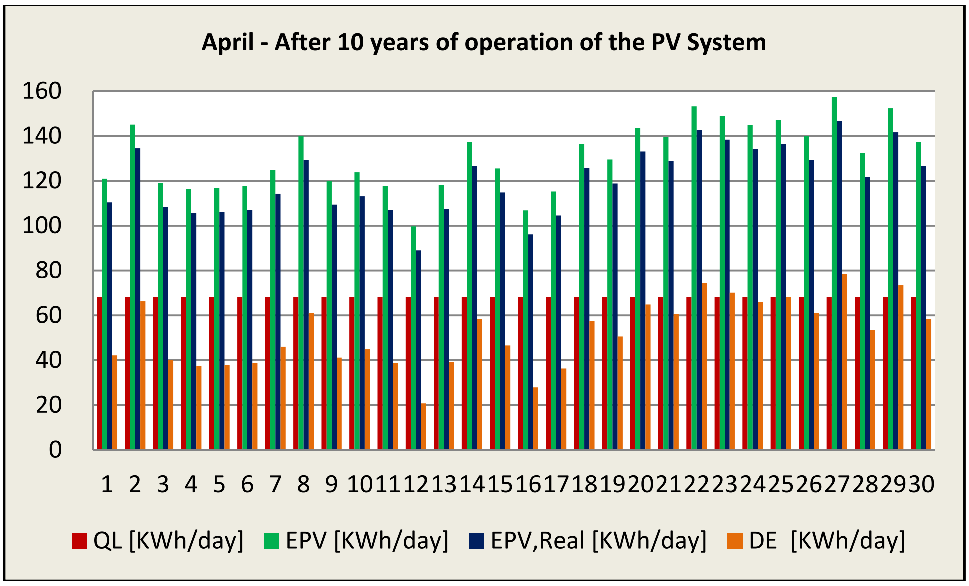

November - After 1 year of operation of the PV System
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

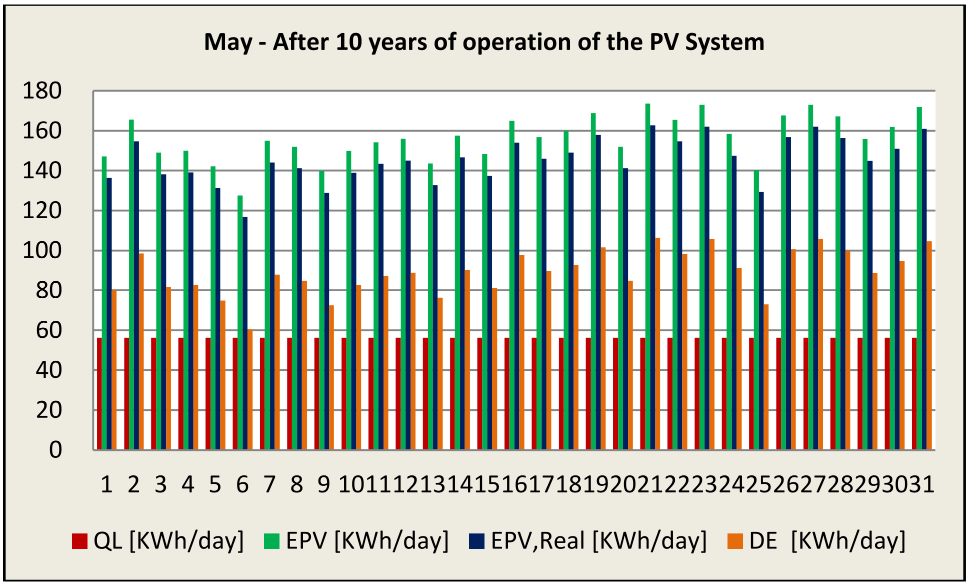

December - After 1 year of operation of the PV System
100
80
60
40
20
0
-20
-40
-60
-80
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

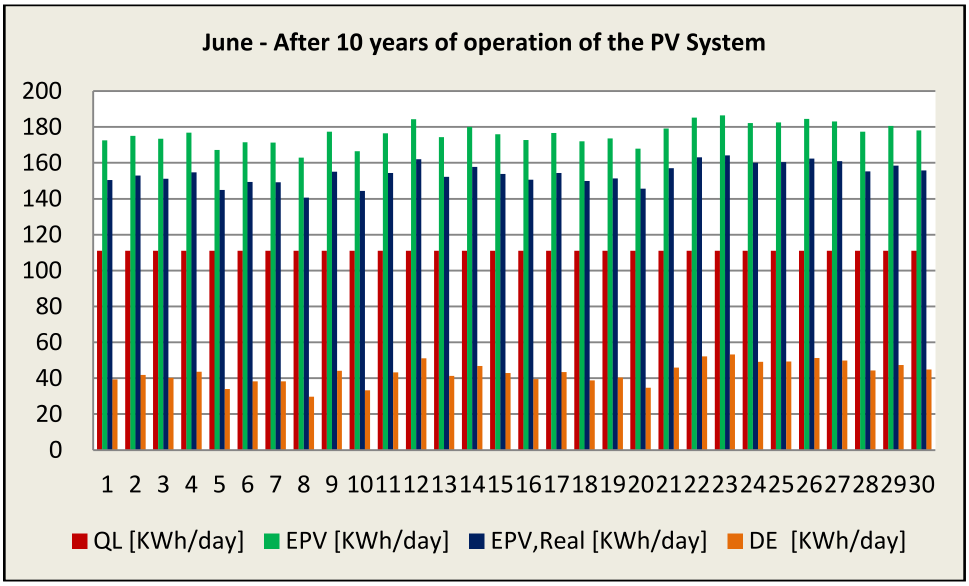

January - After 10 years of operation of the PV System
120
100
80
60
40
20
0
-20
-40
-60
-80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

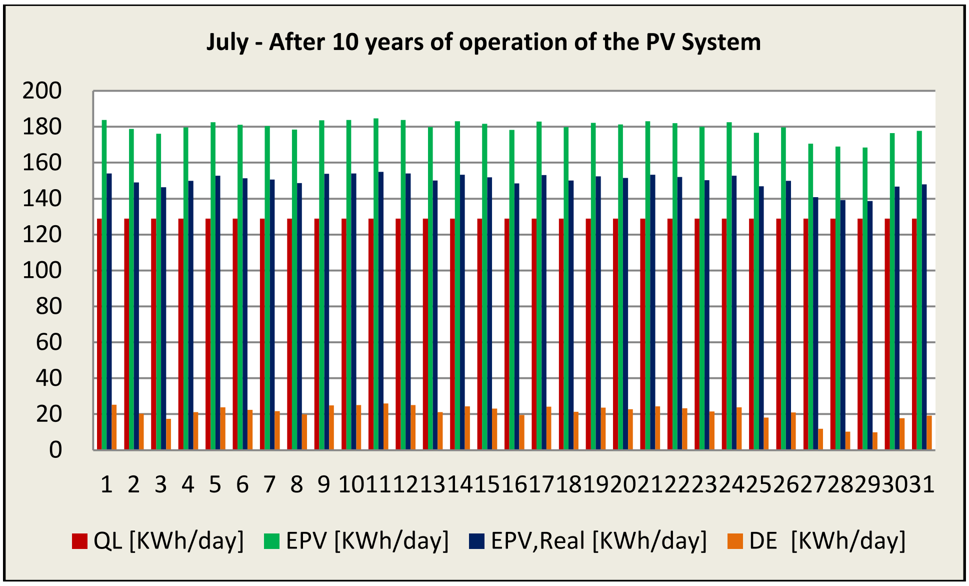

February - After 10 years of operation of the PV System
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

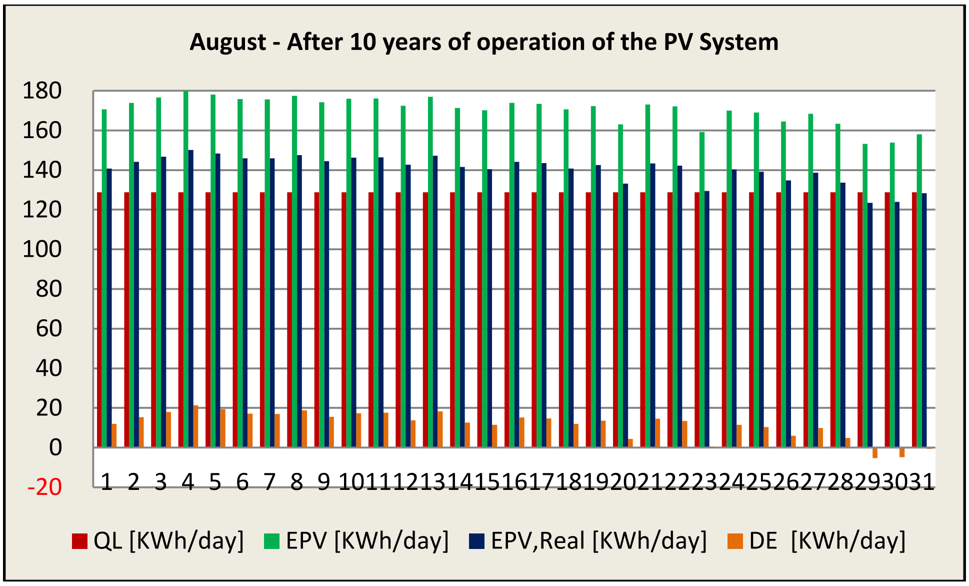

March - After 10 years of operation of the PV System
140
120
100
80
60
40
20
0
-20
-40
-60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

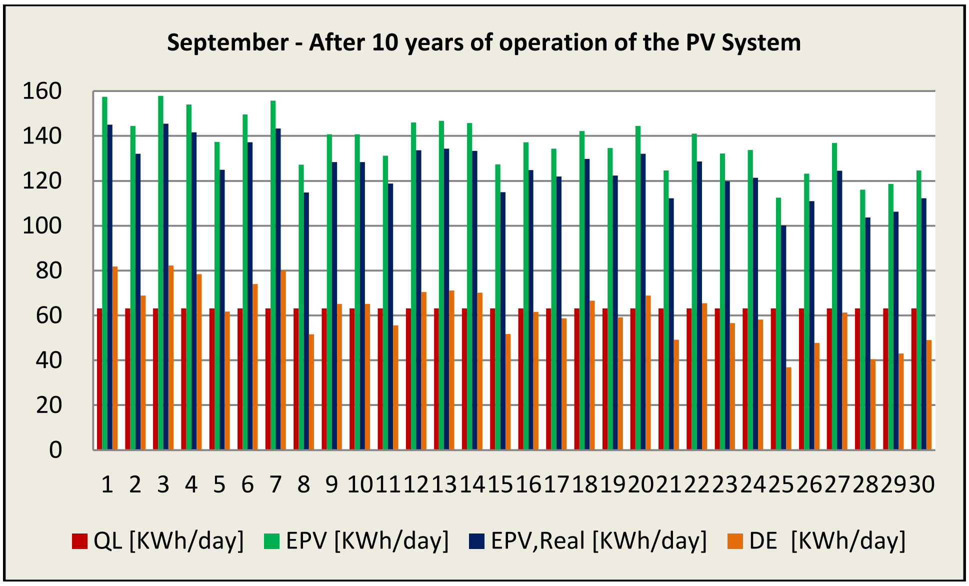

April - After 10 years of operation of the PV System
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

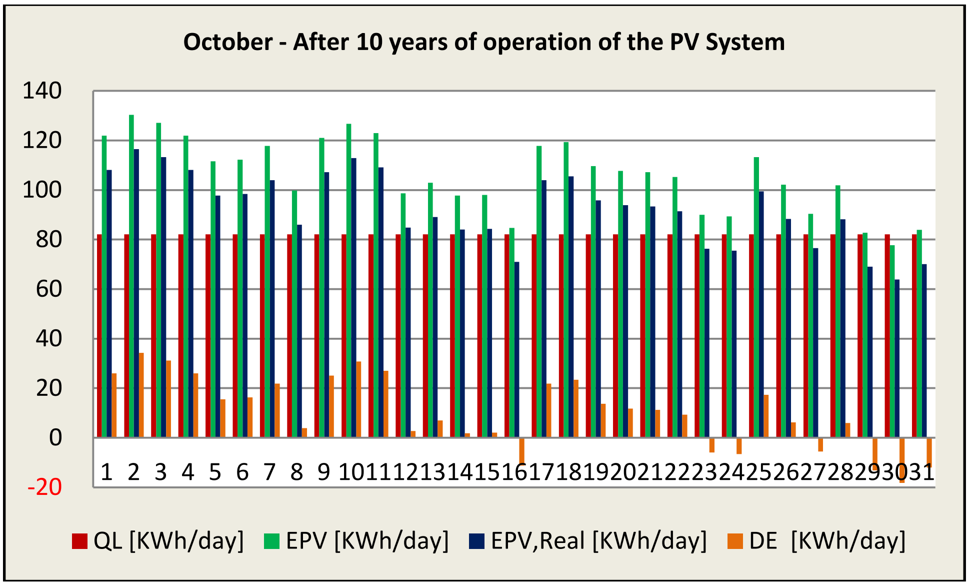

May - After 10 years of operation of the PV System
180
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

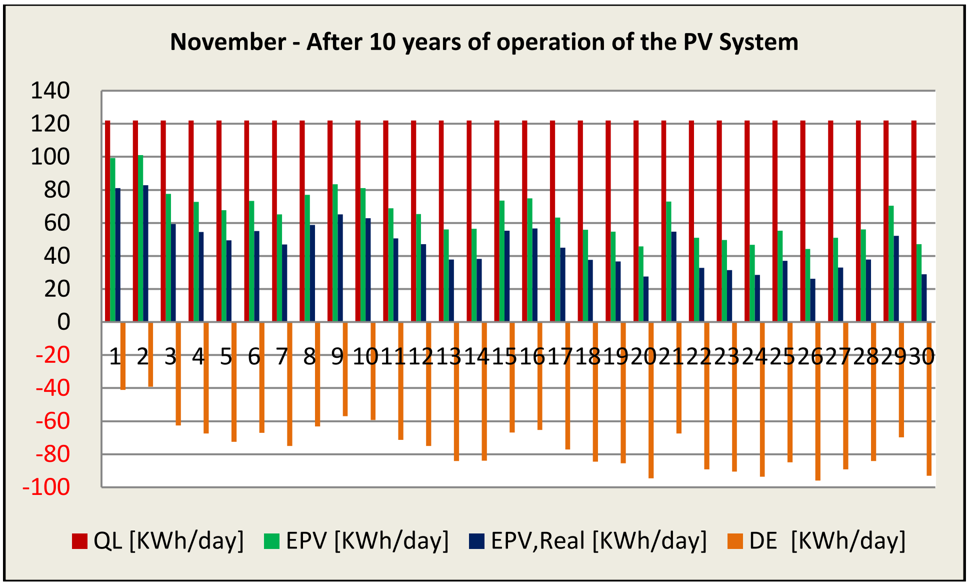

June - After 10 years of operation of the PV System
200
180
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

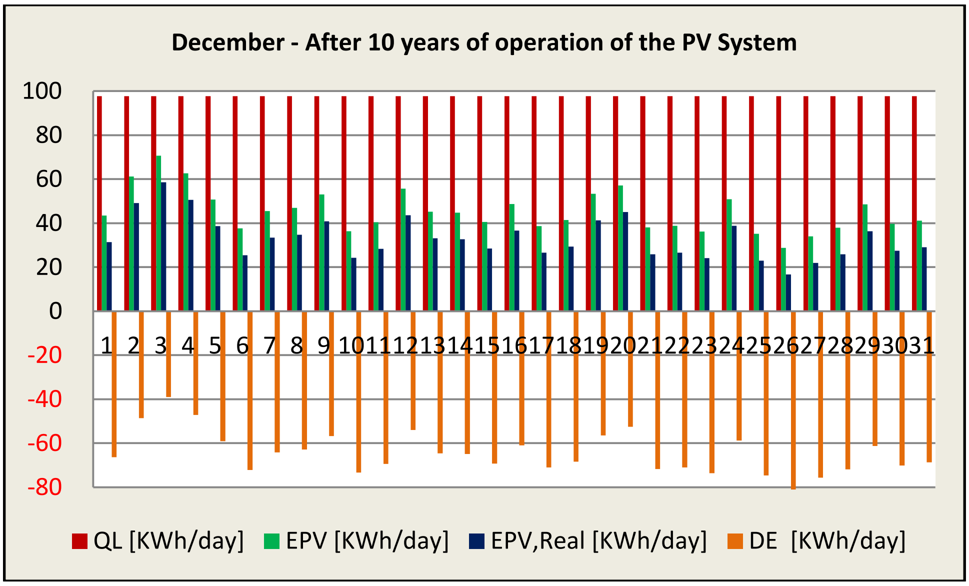

July - After 10 years of operation of the PV System
200
180
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

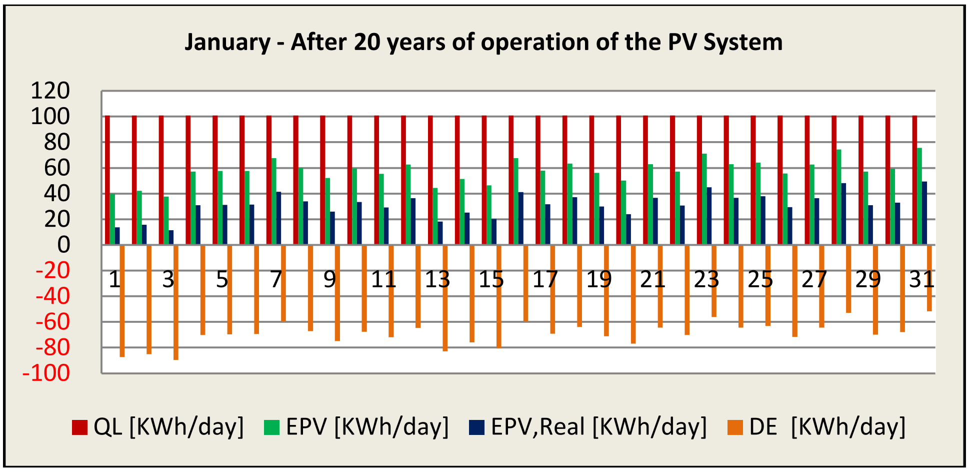

August - After 10 years of operation of the PV System
180
160
140
120
100
80
60
40
20
0
-20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

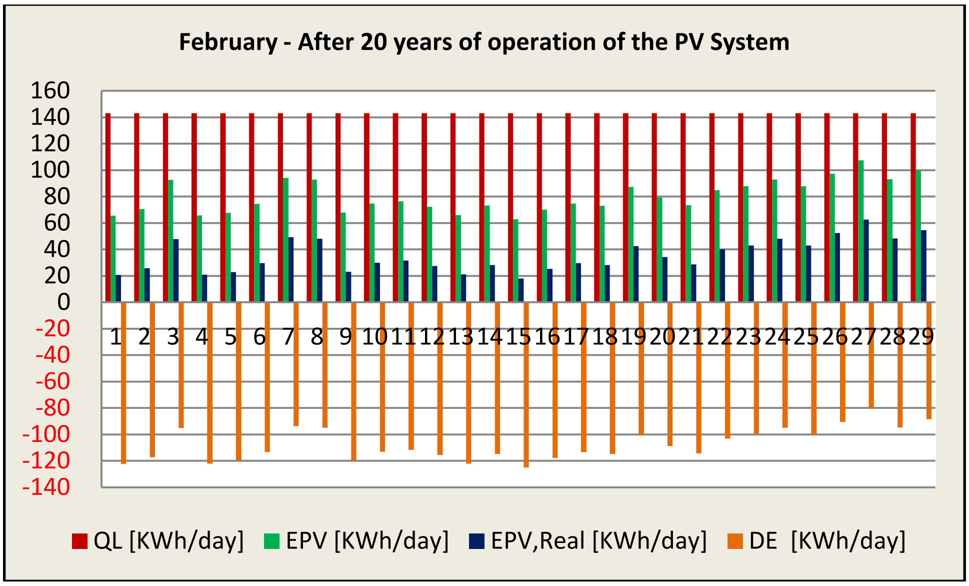

September - After 10 years of operation of the PV System
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

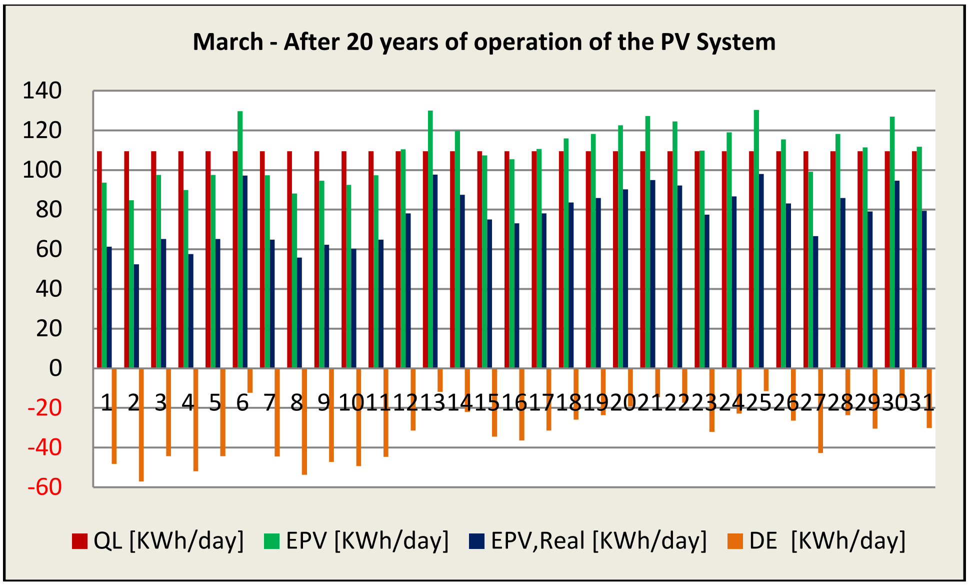

October - After 10 years of operation of the PV System
140
120
100
80
60
40
20
0
-20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

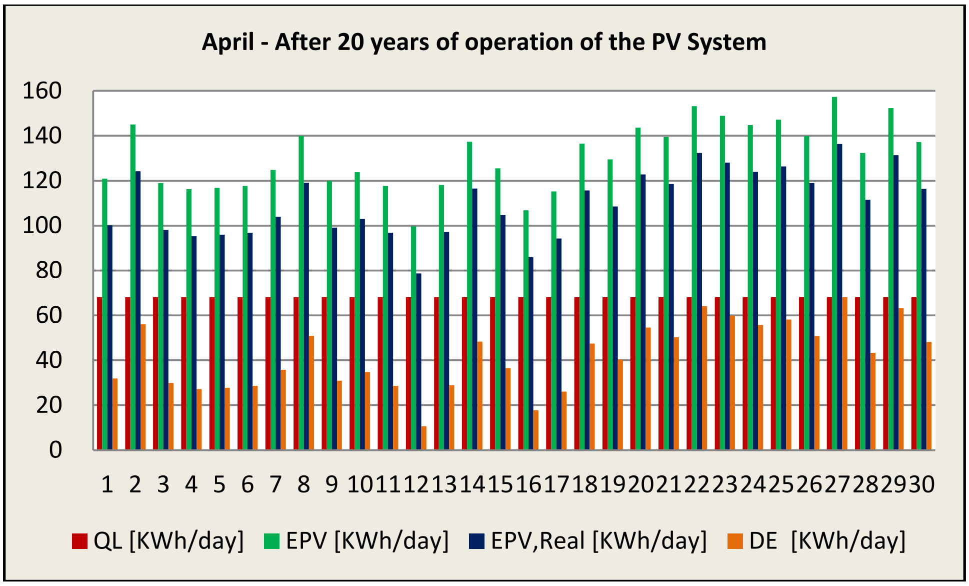

November - After 10 years of operation of the PV System
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

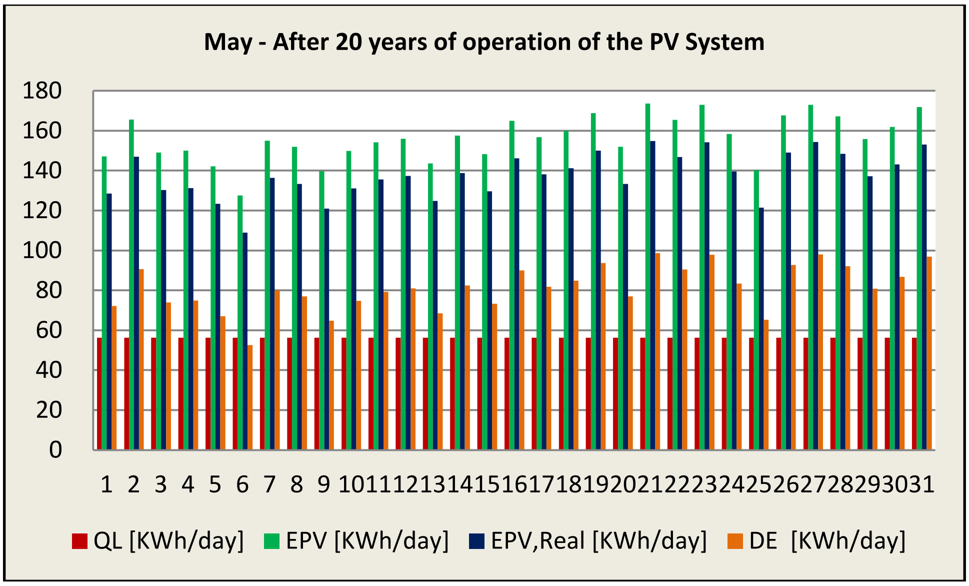

December - After 10 years of operation of the PV System
100
80
60
40
20
0
-20
-40
-60
-80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

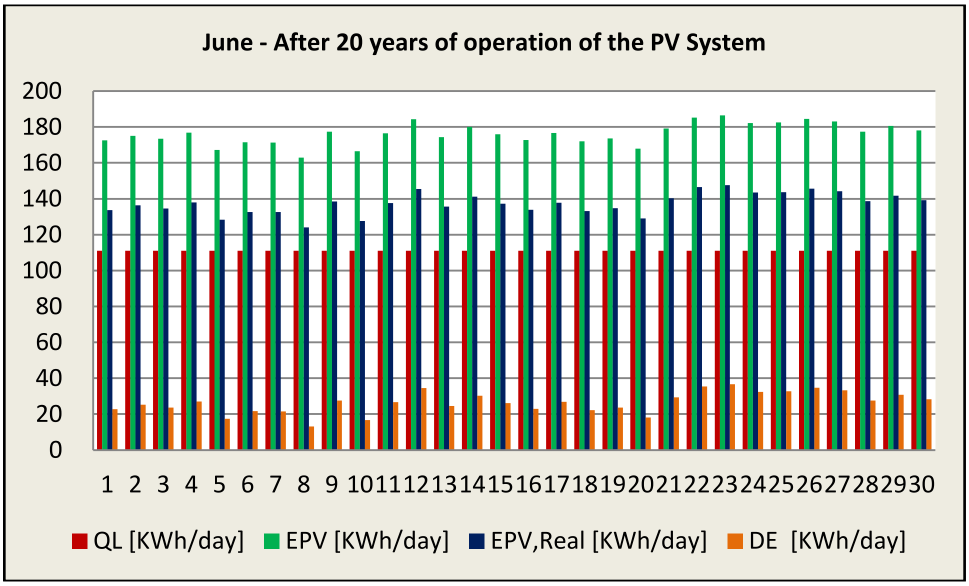

January - After 20 years of operation of the PV System
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

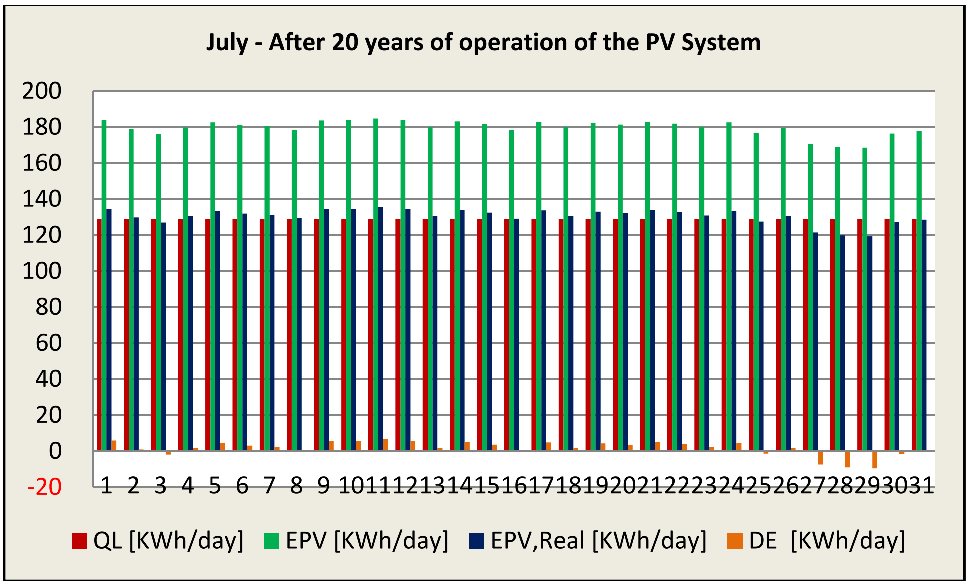

February - After 20 years of operation of the PV System
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

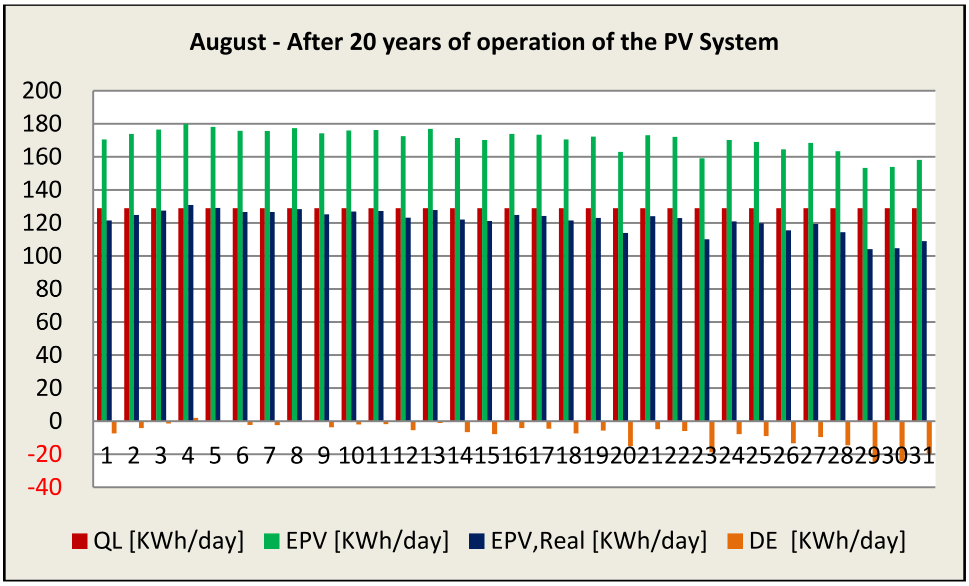

March - After 20 years of operation of the PV System
140
120
100
80
60
40
20
0
-20
-40
-60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day] EPV [KWh/day] EPV,Real [KWh/day] DE [KWh/day]

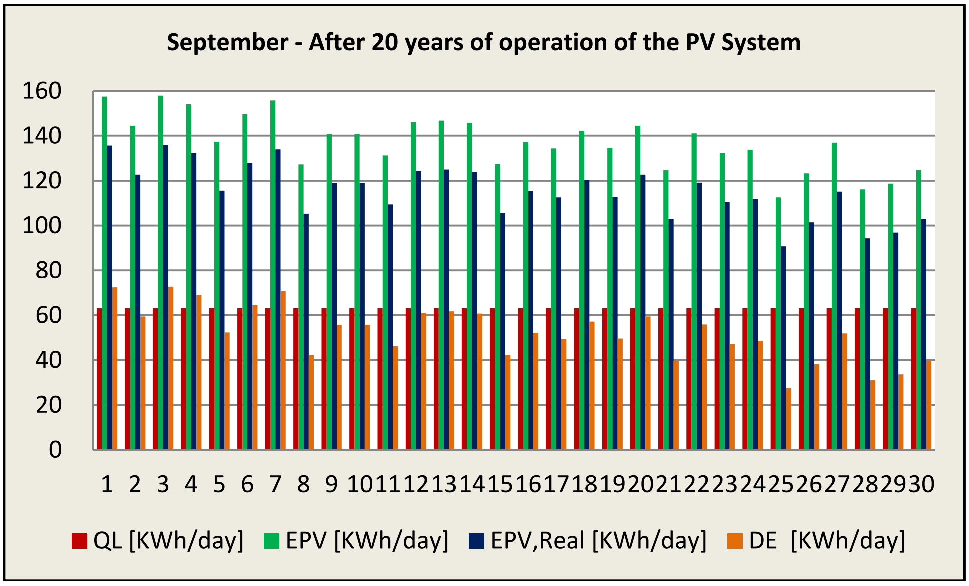

April - After 20 years of operation of the PV System
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

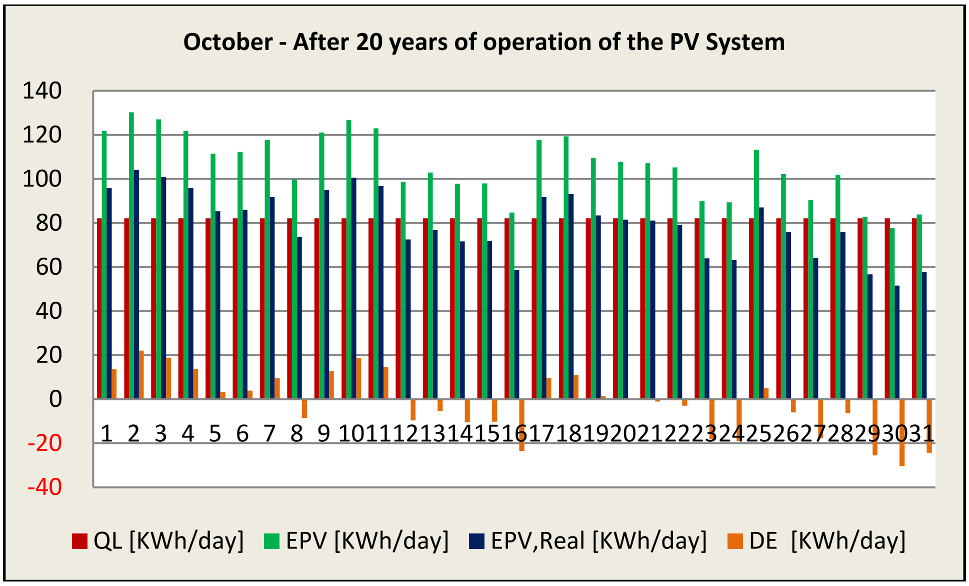

May - After 20 years of operation of the PV System
180
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

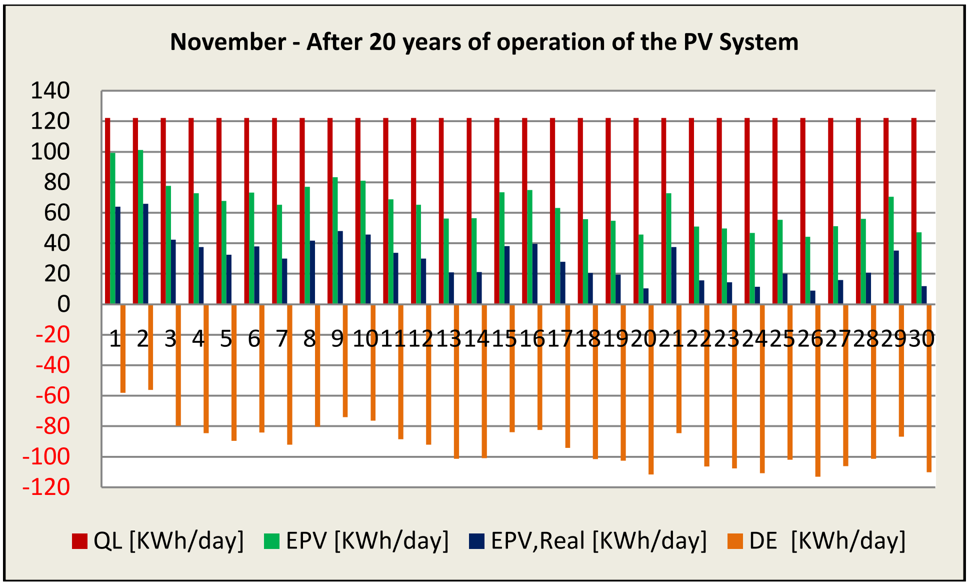

June - After 20 years of operation of the PV System
200
180
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

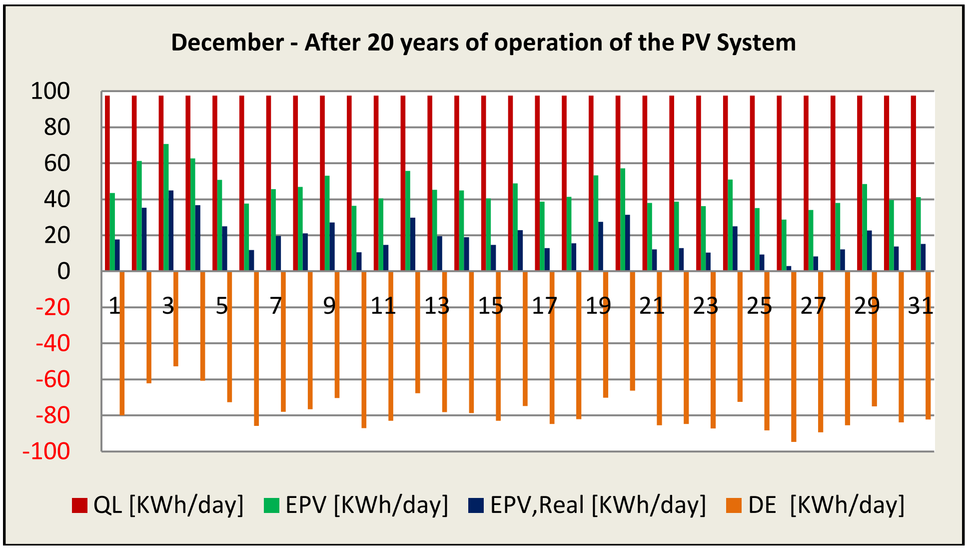

July - After 20 years of operation of the PV System
200
180
160
140
120
100
80
60
40
20
0
-20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]


August - After 20 years of operation of the PV System
200
180
160
140
120
100
80
60
40
20
0
-20
-40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

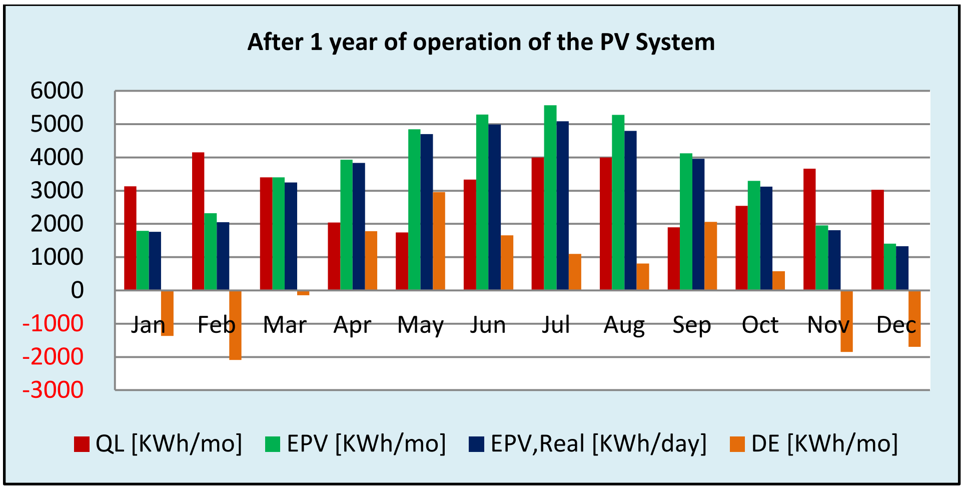

September - After 20 years of operation of the PV System
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
QL [KWh/day]
EPV [KWh/day]
EPV,Real [KWh/day]
DE [KWh/day]

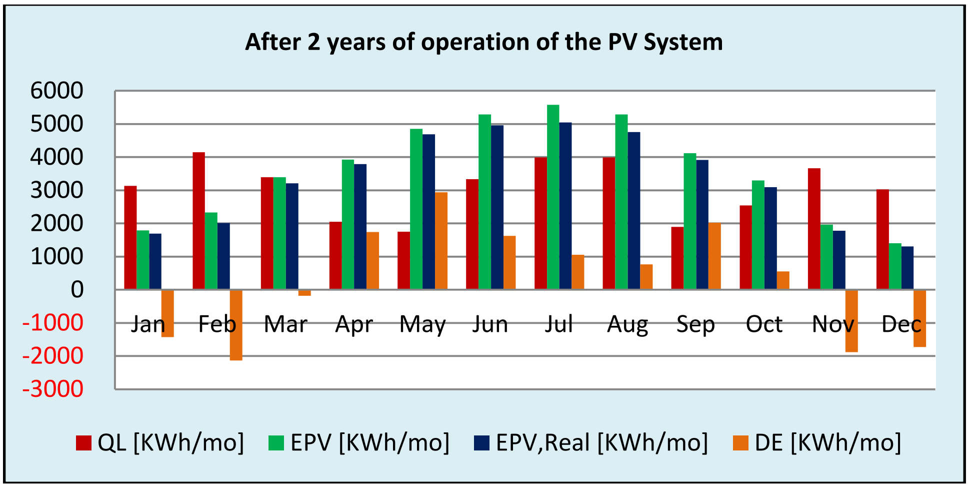


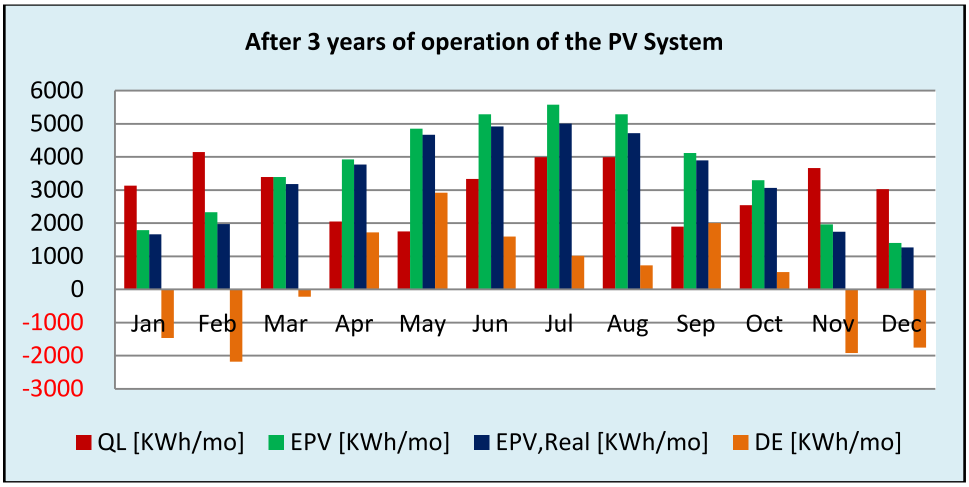


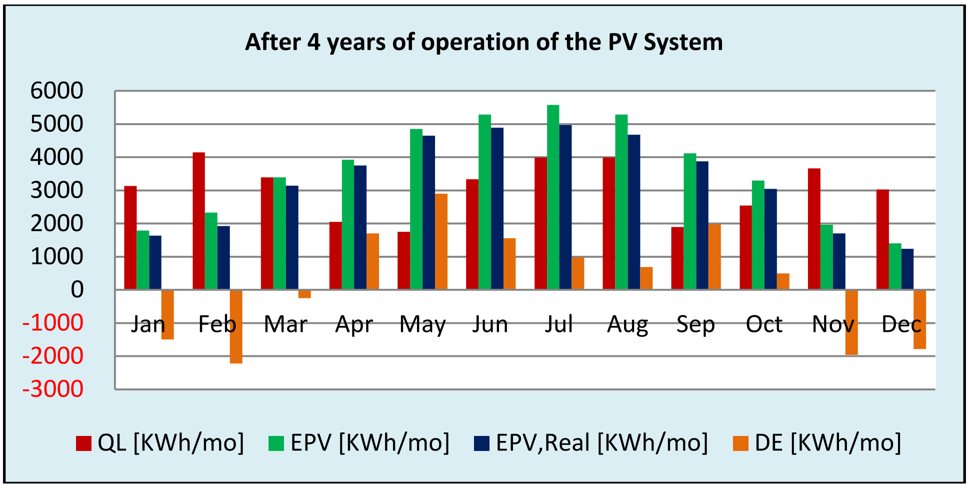


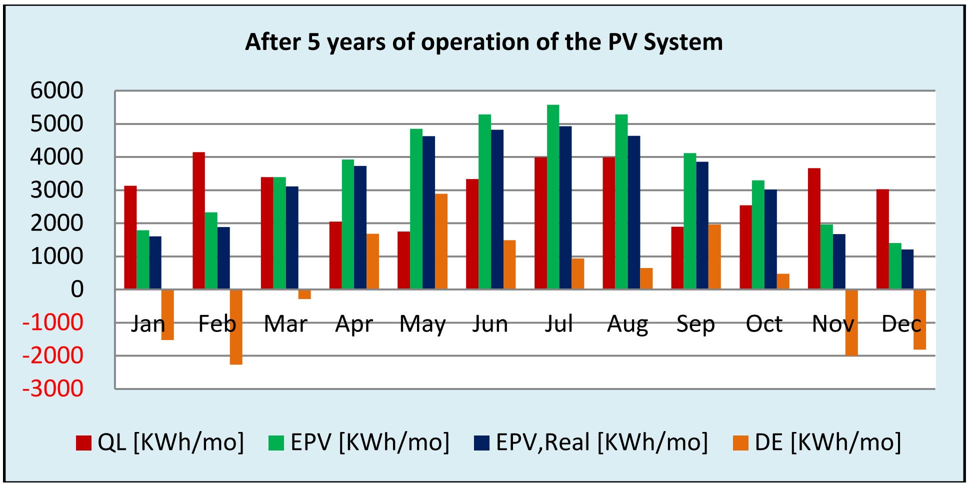
Graph 1: Simulation for the parameters Q_L, E_{pv}, $E_{PV,Real}$ and DE for three years indicatively (1st, 10th & 20th year), for all days of all months → [KWh/day]

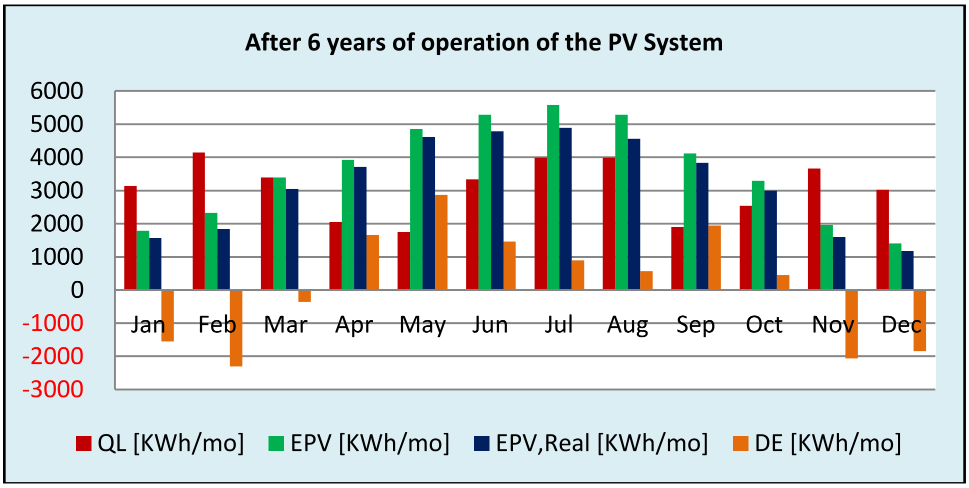

After 1 year of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/day] DE [KWh/mo]

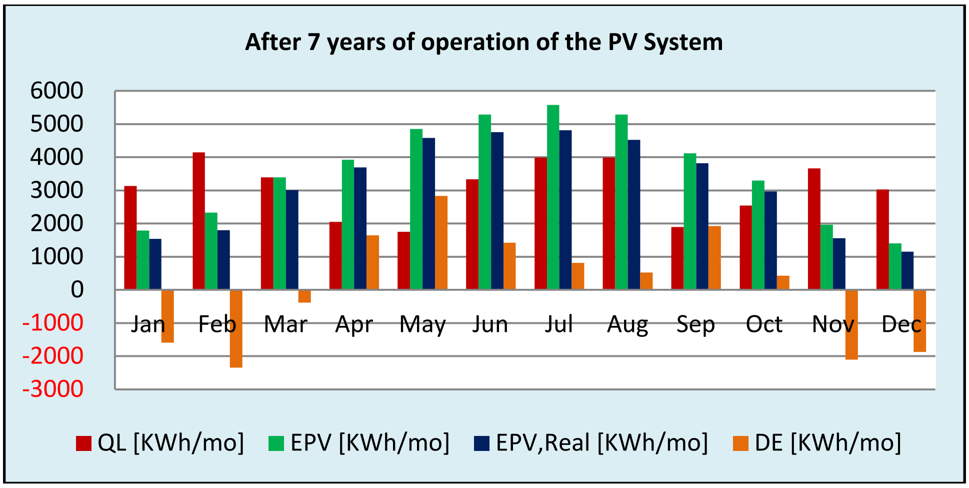

After 2 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/mo] DE [KWh/mo]

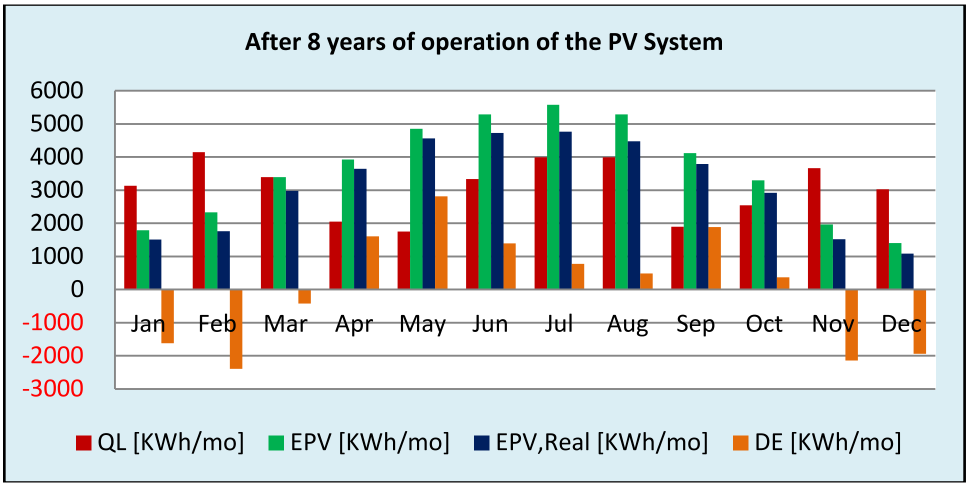

After 3 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/mo] DE [KWh/mo]

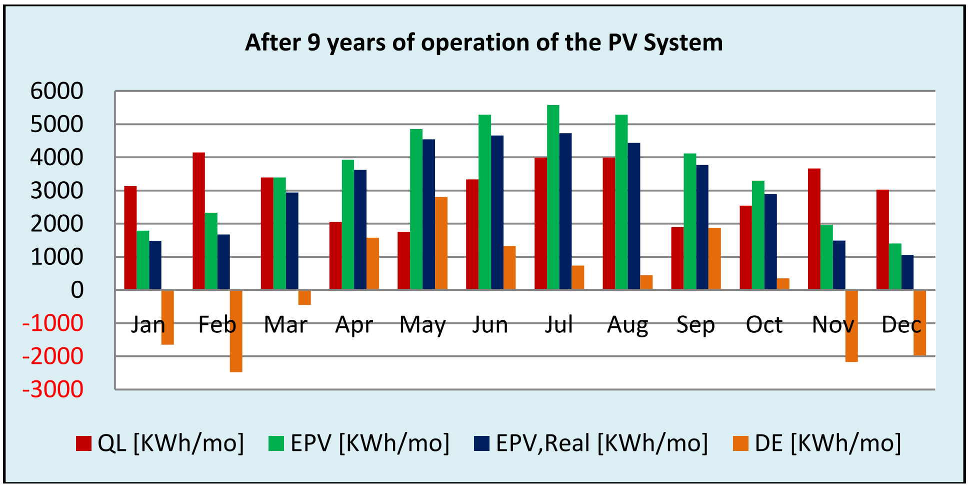

After 4 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

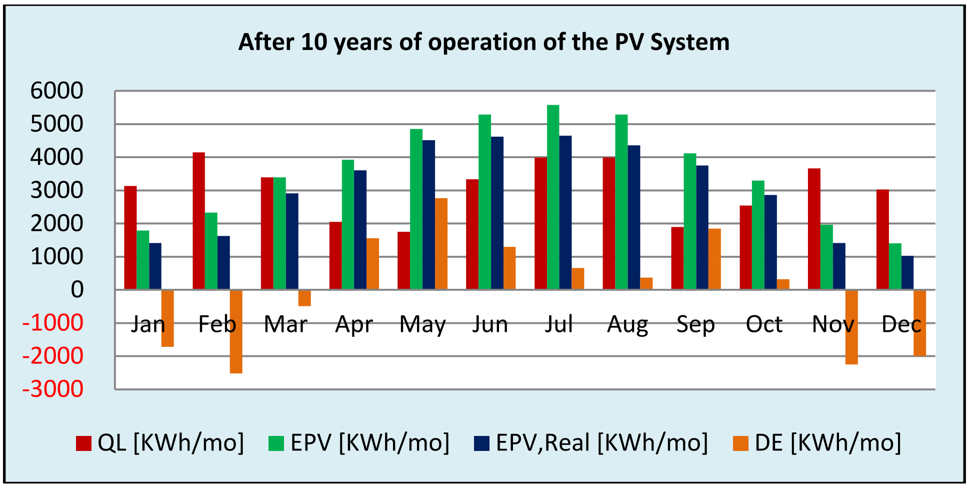

After 5 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

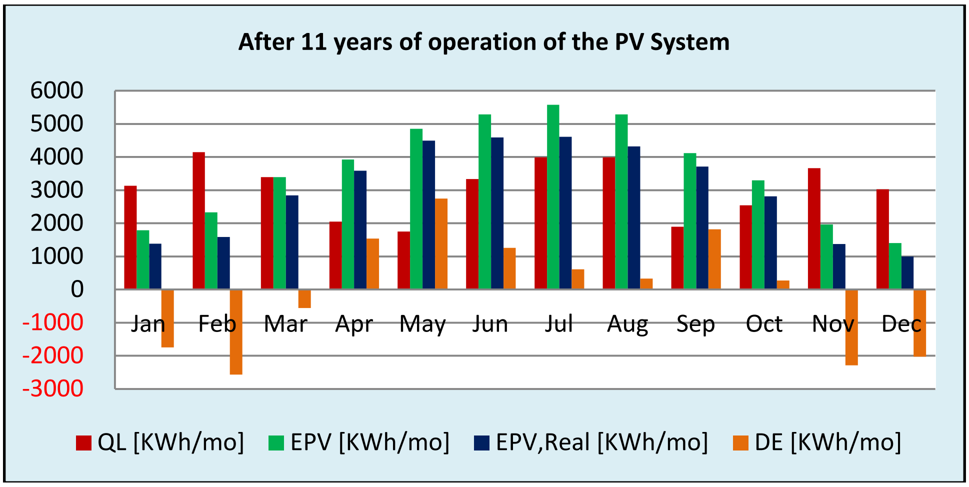

After 6 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

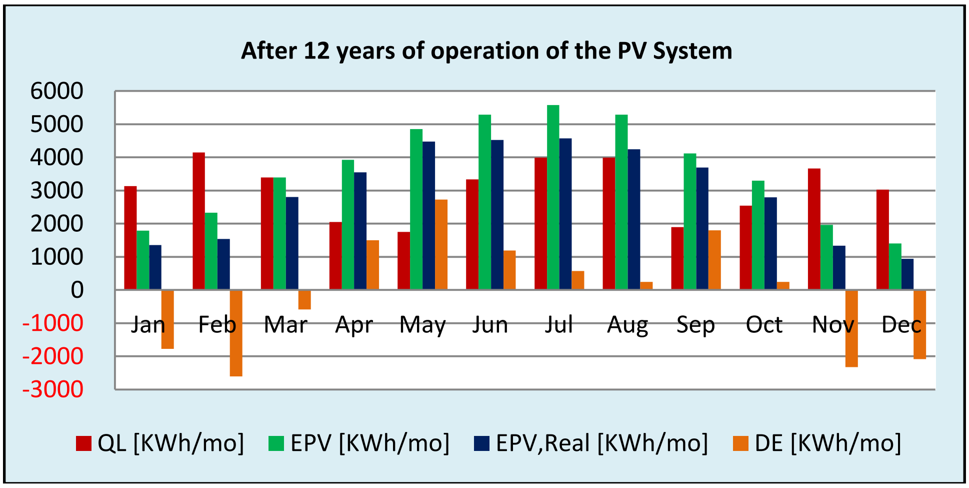

After 7 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/mo] DE [KWh/mo]

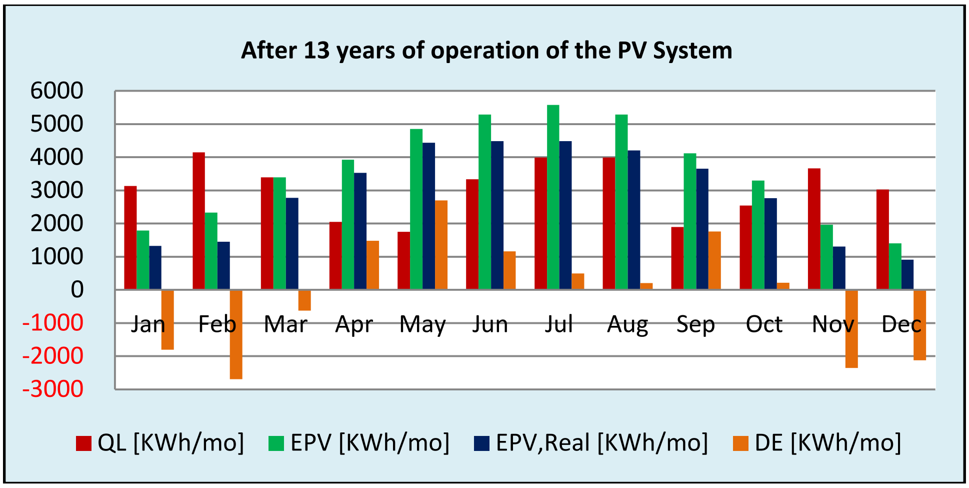

After 8 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/mo] DE [KWh/mo]

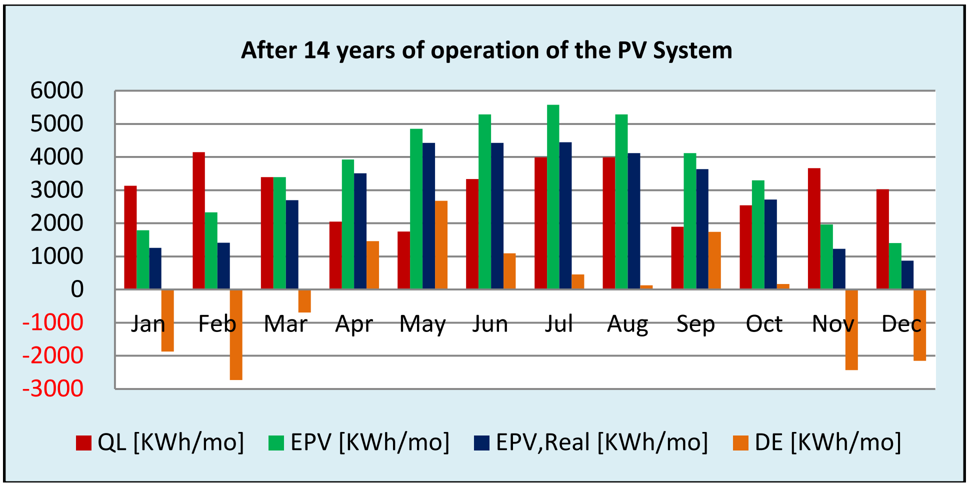

After 9 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/mo] DE [KWh/mo]

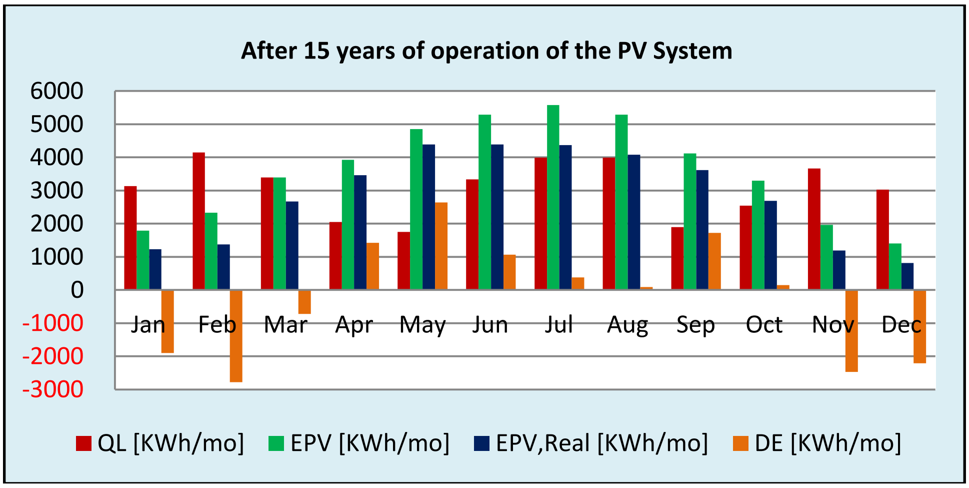

After 10 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

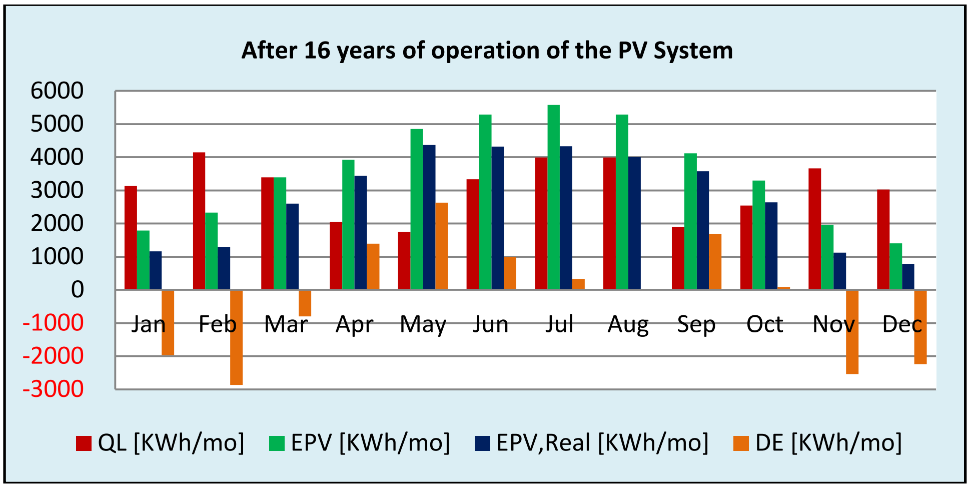

After 11 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

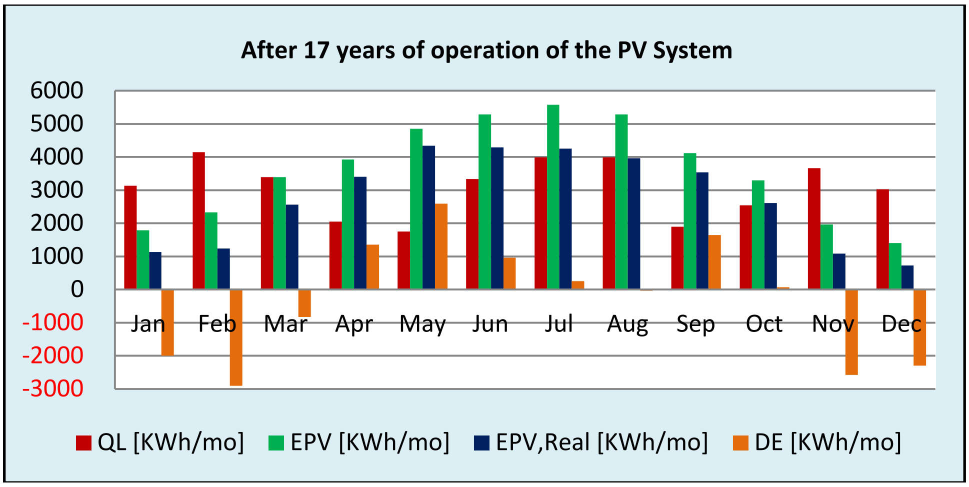

After 12 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

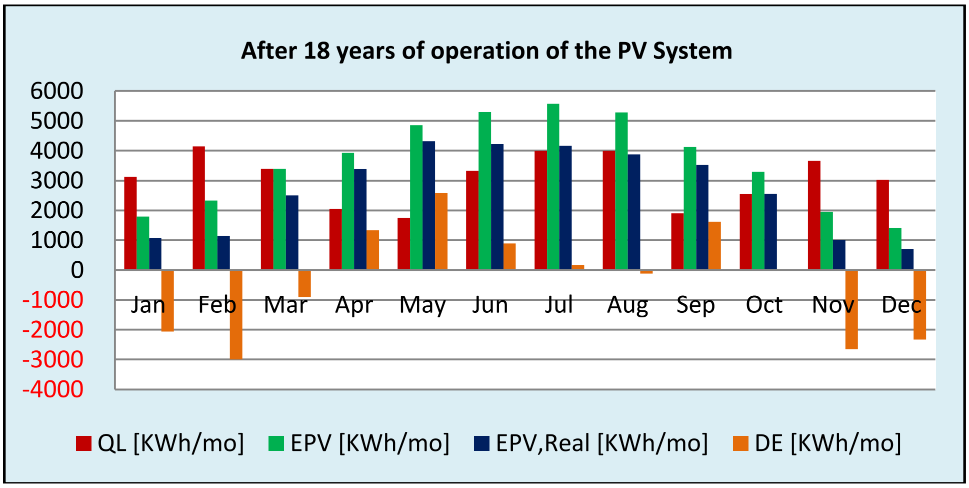

After 13 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

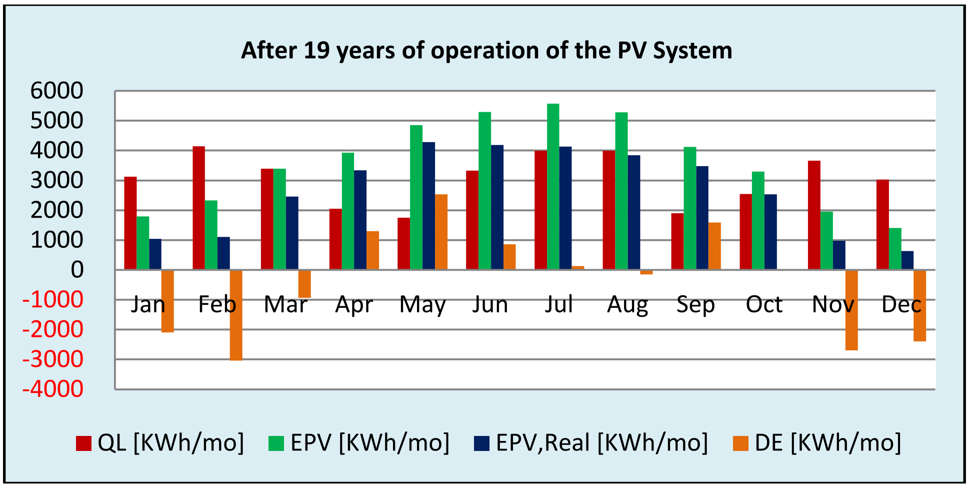

After 14 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

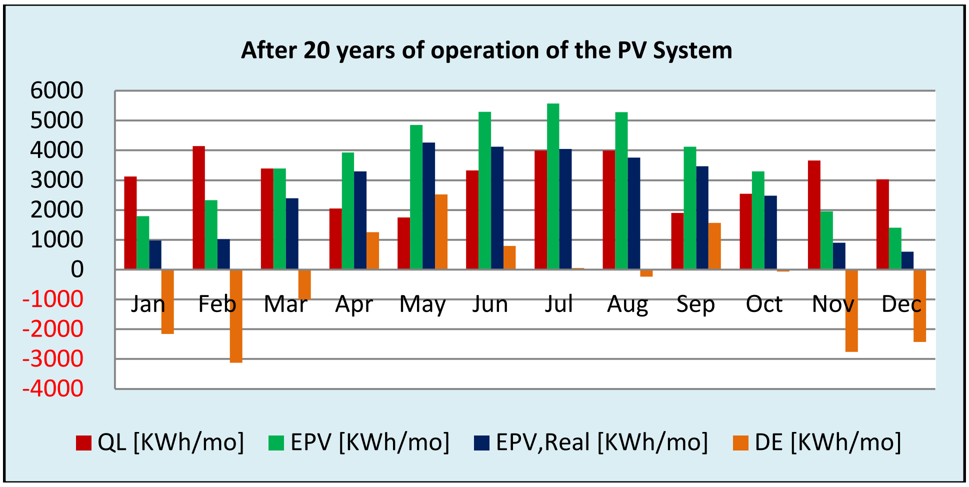

After 15 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]


After 16 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/mo] DE [KWh/mo]

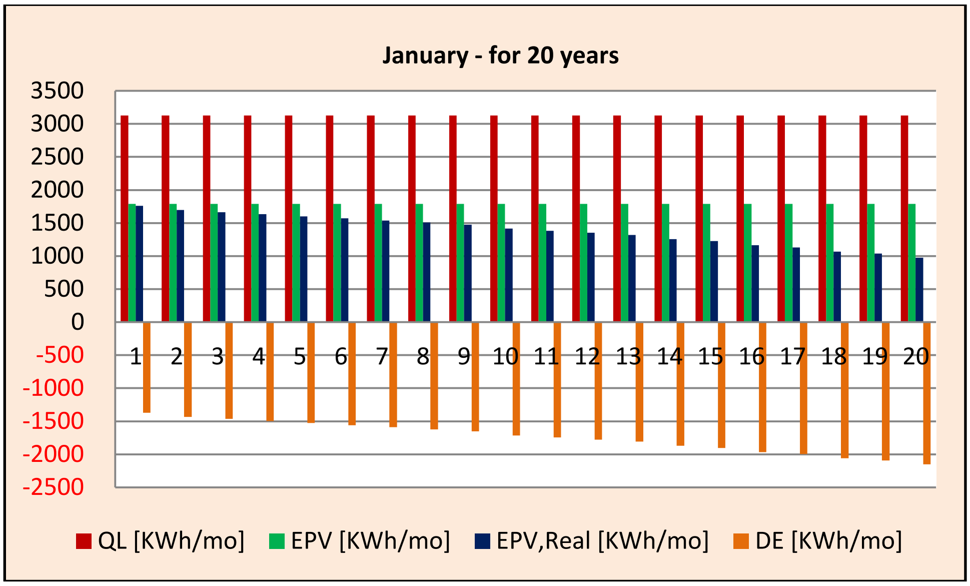

After 17 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/mo] DE [KWh/mo]

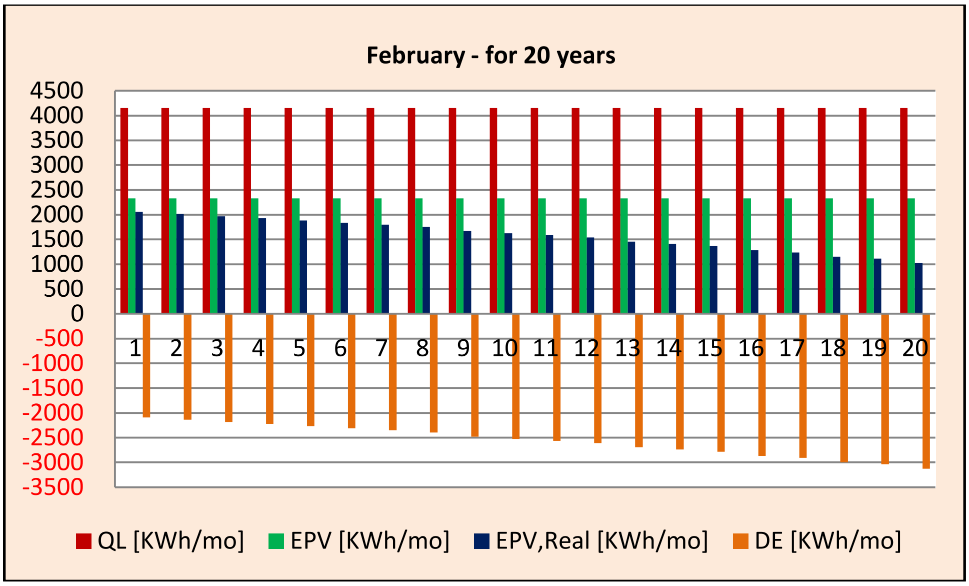

After 18 years of operation of the PV System
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
QL [KWh/mo] EPV [KWh/mo] EPV,Real [KWh/mo] DE [KWh/mo]

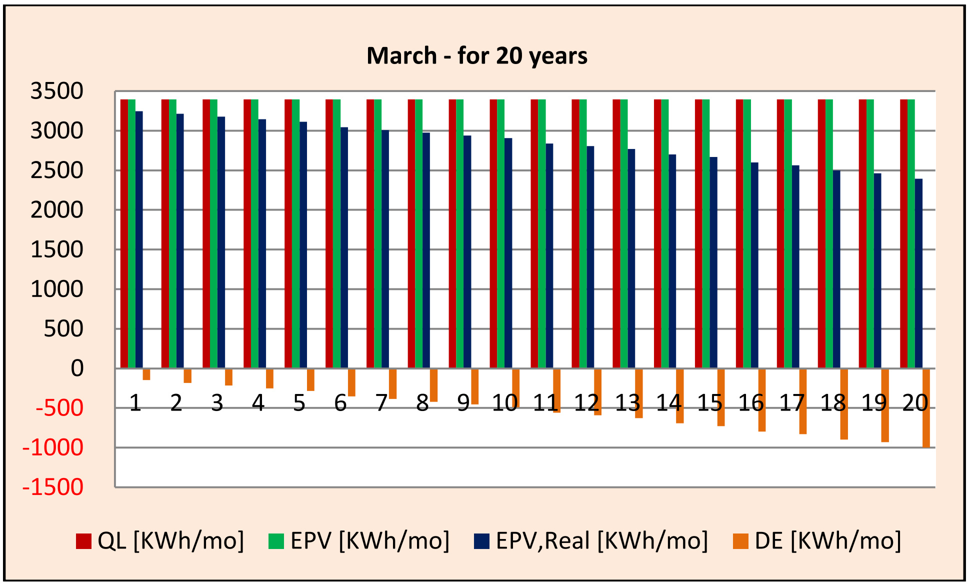


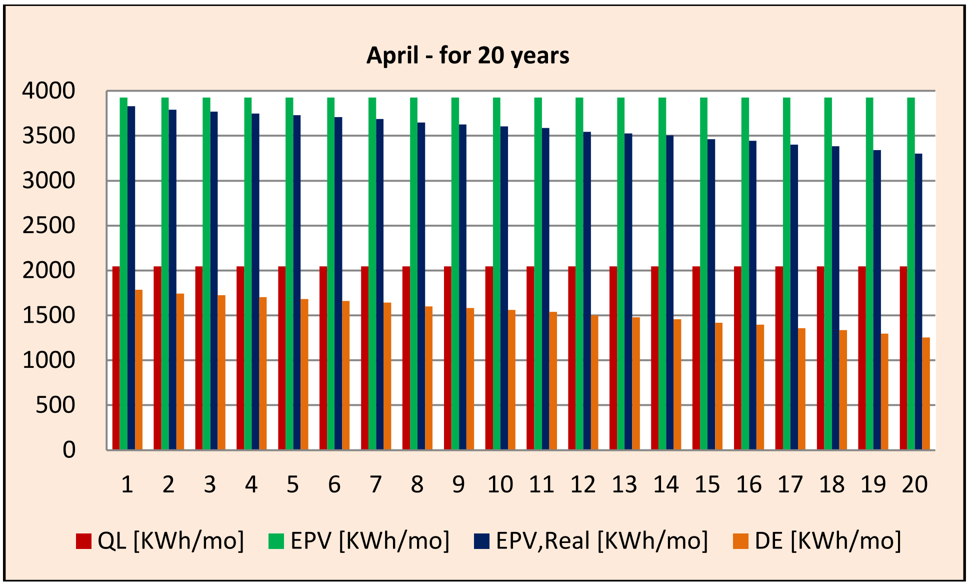


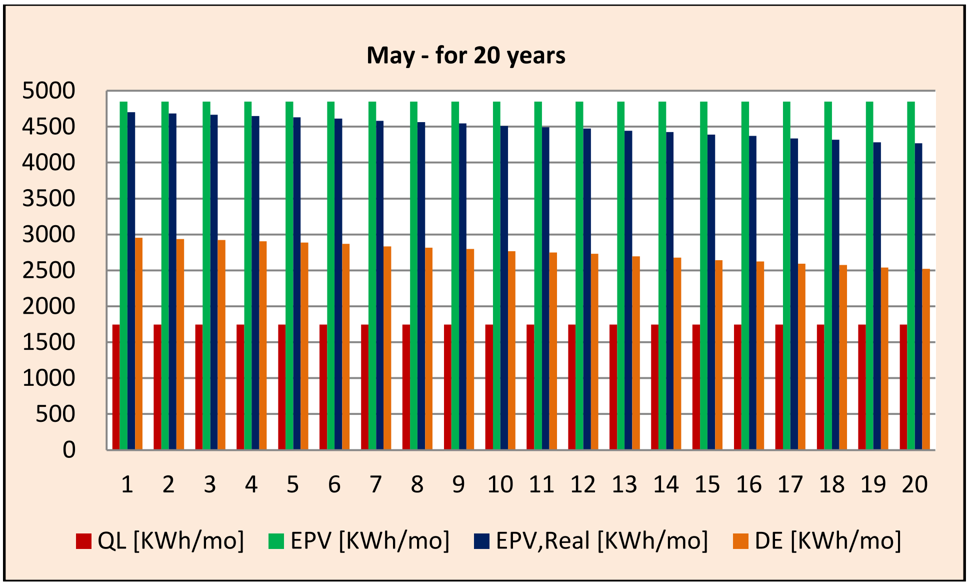
Graph 2: Monthly values for the parameters Q_L, E_{pv}, $E_{PV,Real}$ and DE for 20 years of operation of the PV System (considering all the months together) → [KWh/year]

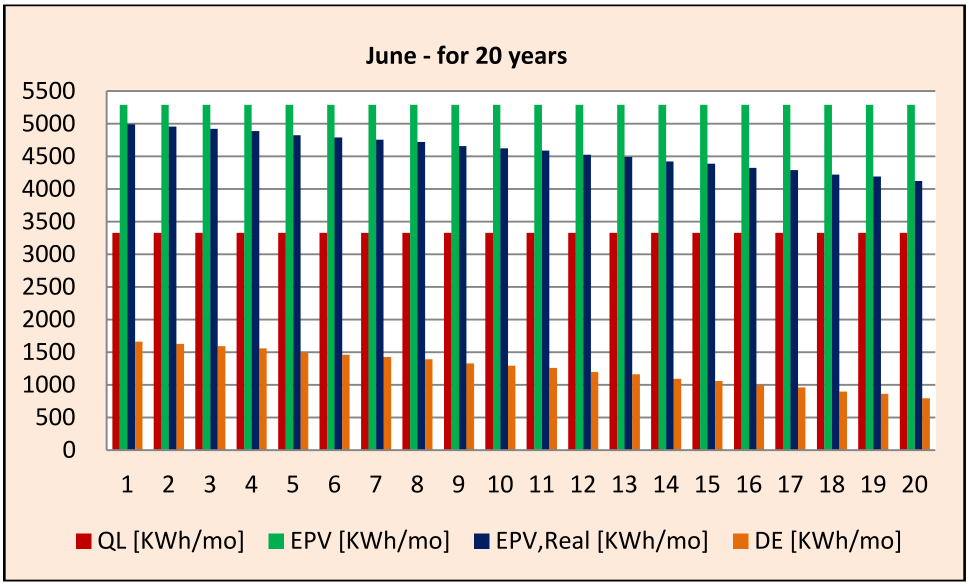

January - for 20 years
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

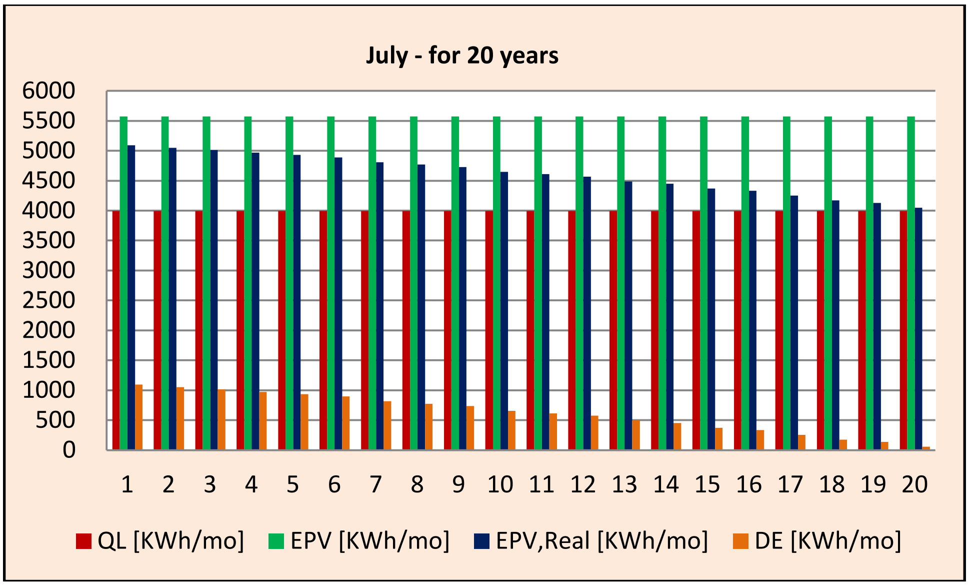

February - for 20 years
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

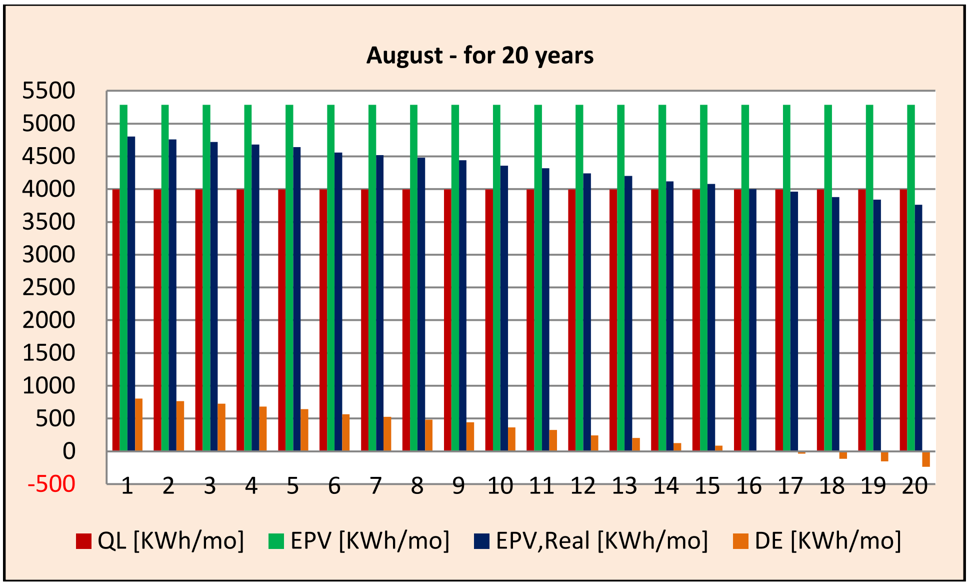

March - for 20 years
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

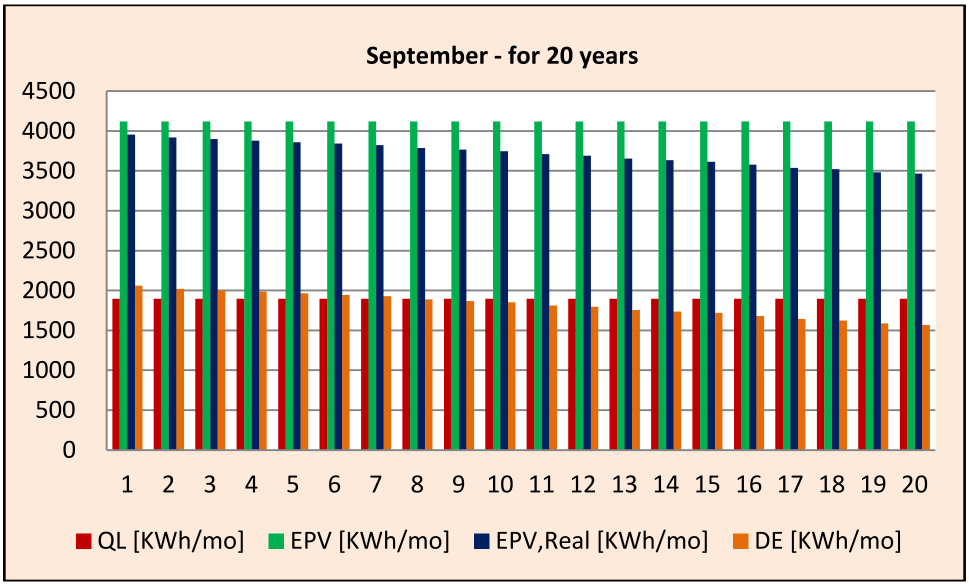

April - for 20 years
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

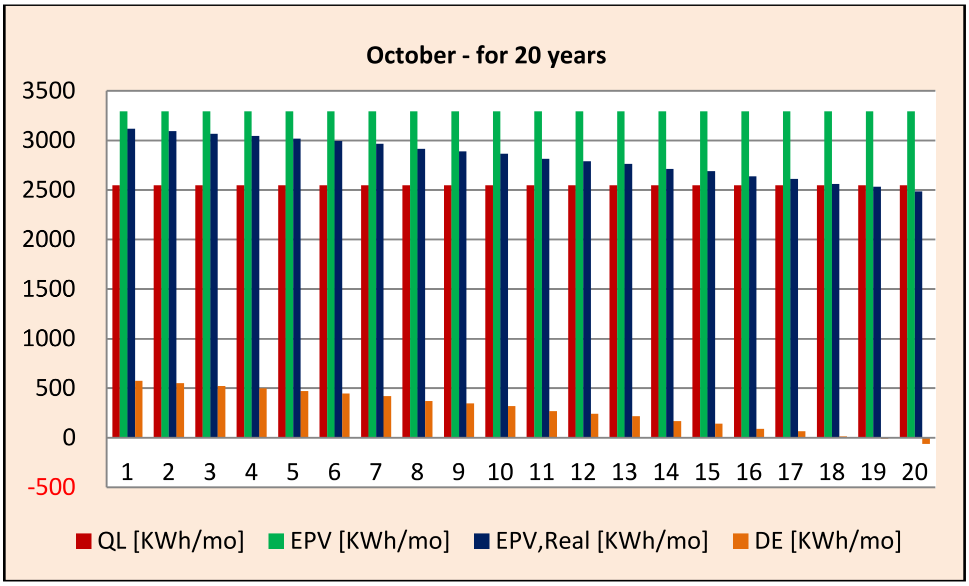

May - for 20 years
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

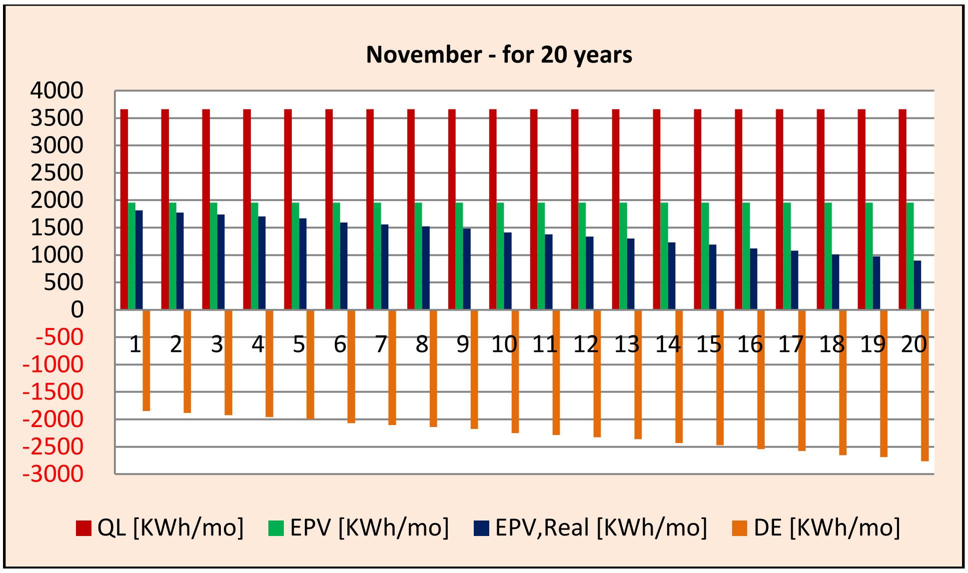

June - for 20 years
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

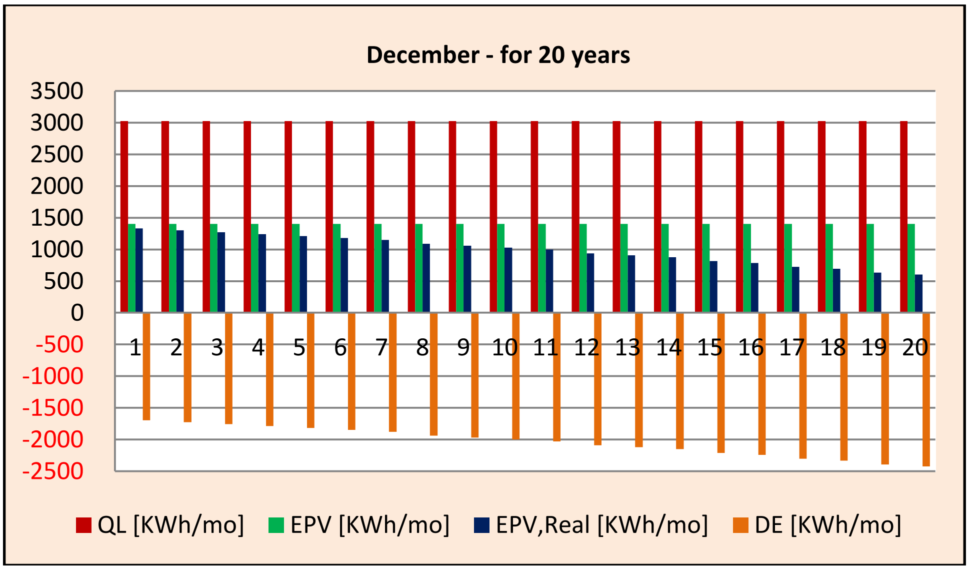

July - for 20 years
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]


August - for 20 years
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]

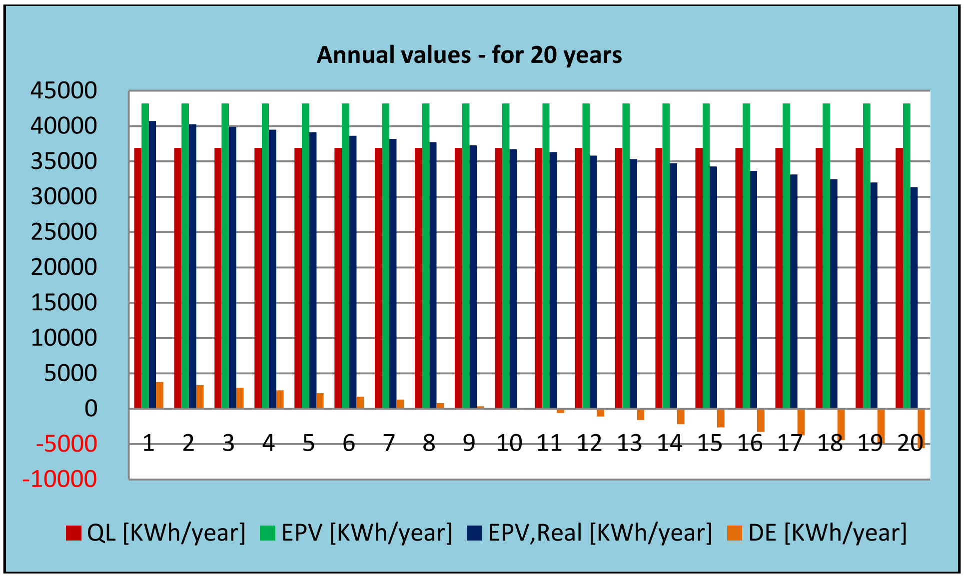

September - for 20 years
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
QL [KWh/mo]
EPV [KWh/mo]
EPV,Real [KWh/mo]
DE [KWh/mo]



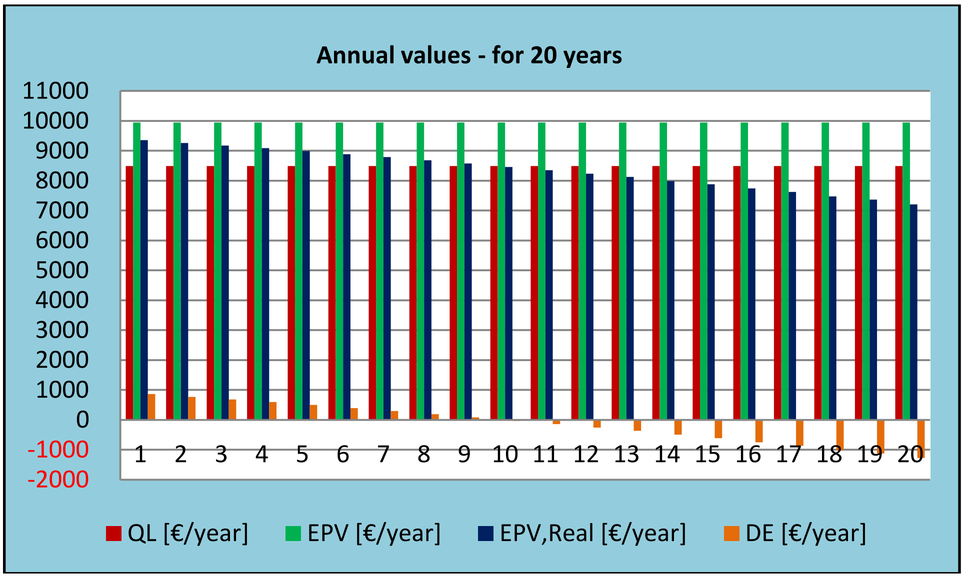




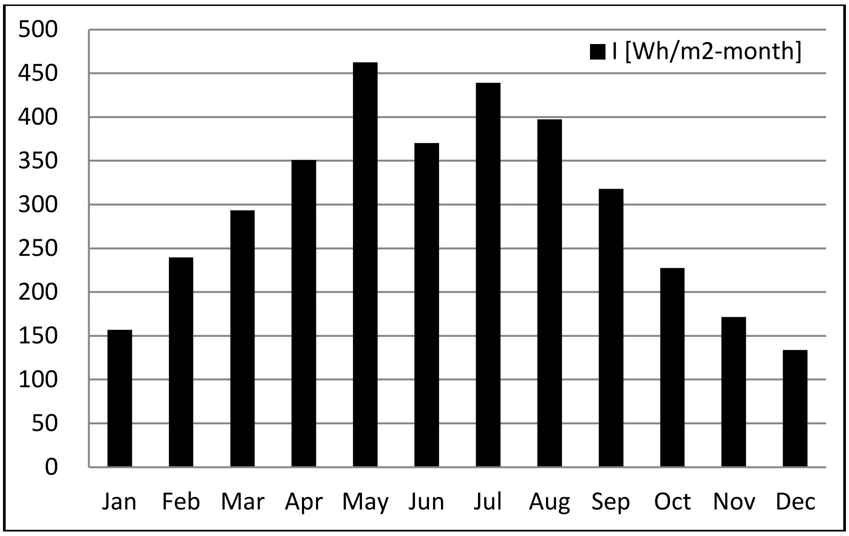
Graph 3: Monthly values for the parameters Q_L, E_{pv}, $E_{PV,Real}$ and DE for 20 years of operation of the PV System (considering each month separately) → [KWh/year]



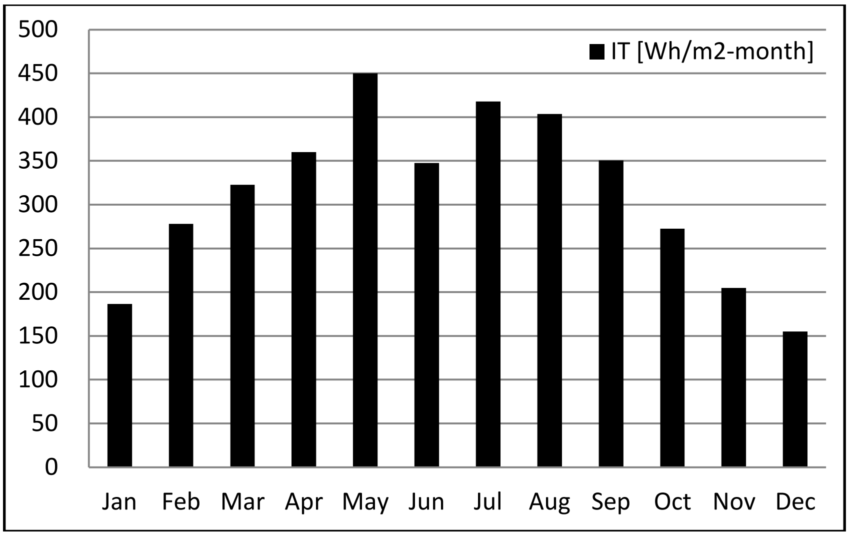
Graph 4a: Annual average values for the parameters Q_L, E_{pv}, $E_{PV,Real}$ and DE for 20 years of operation of the PV System → [KWh/year]



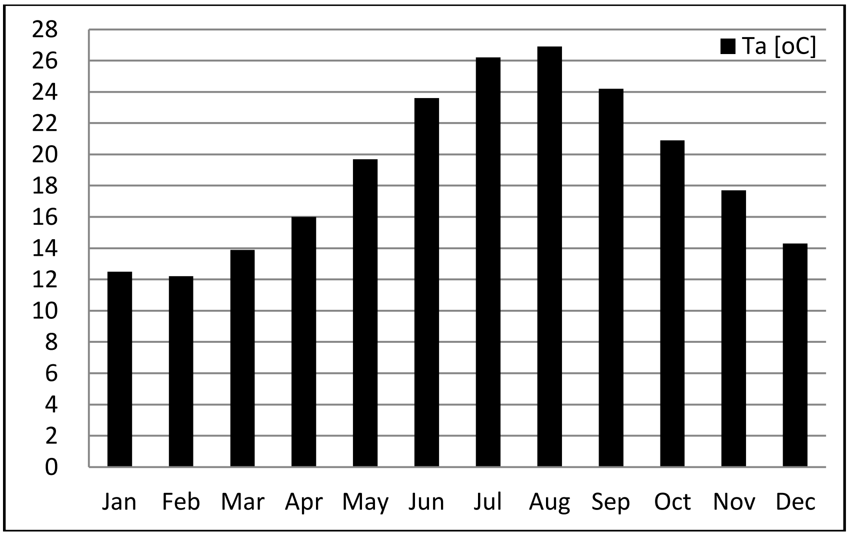
Graph 4b: Annual average values for the parameters Q_L, E_{pv}, $E_{PV,Real}$ and DE for 20 years of operation of the PV System → [€/year]



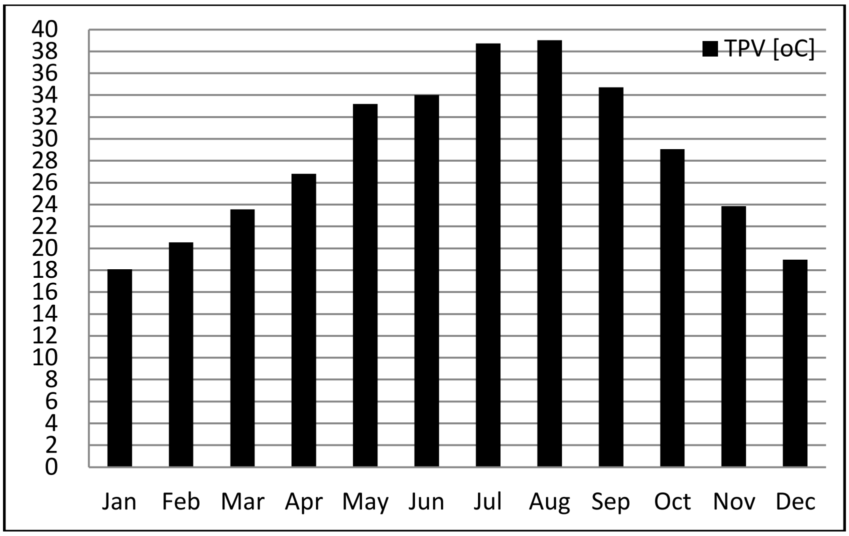
Graph 5a: The mean monthly values of the hourly solar radiation at horizontal, where observed from the hourly data of the years 2004 & 2005, from the database SODA, I [Wh/m^2]



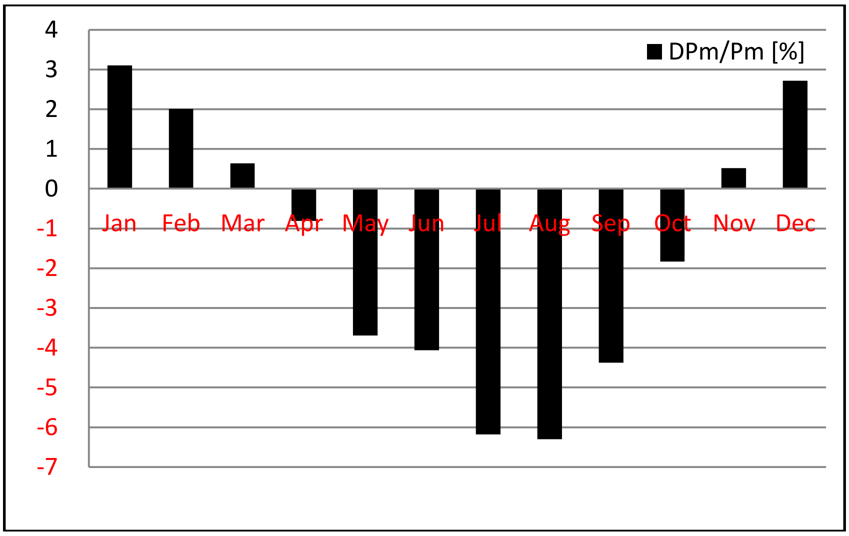
Graph 5b: The mean monthly values of the hourly solar radiation at the inclined surface of photovoltaics (β=25°), where observed from the hourly data of the years 2004 & 2005, from the database SODA, I_T [Wh/m^2]



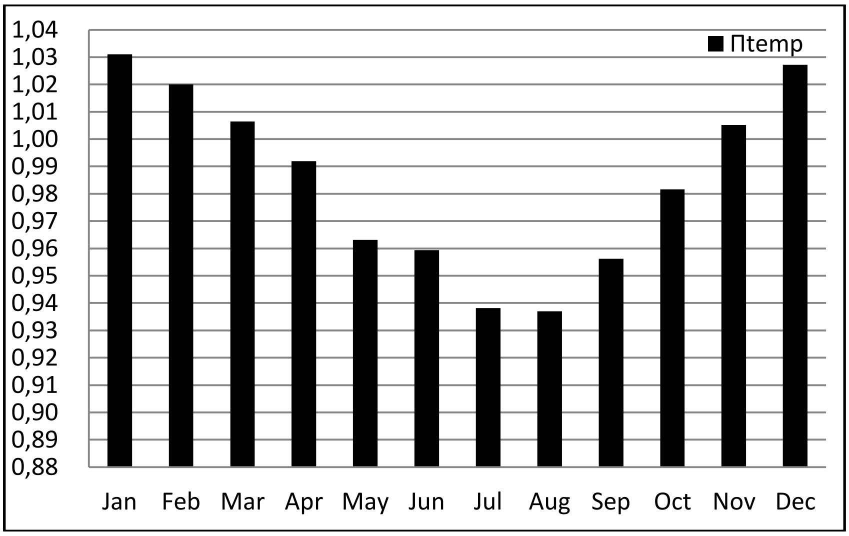
Graph 5c: The mean monthly daily ambient temperature from the database PVGIS, T_a [°C]



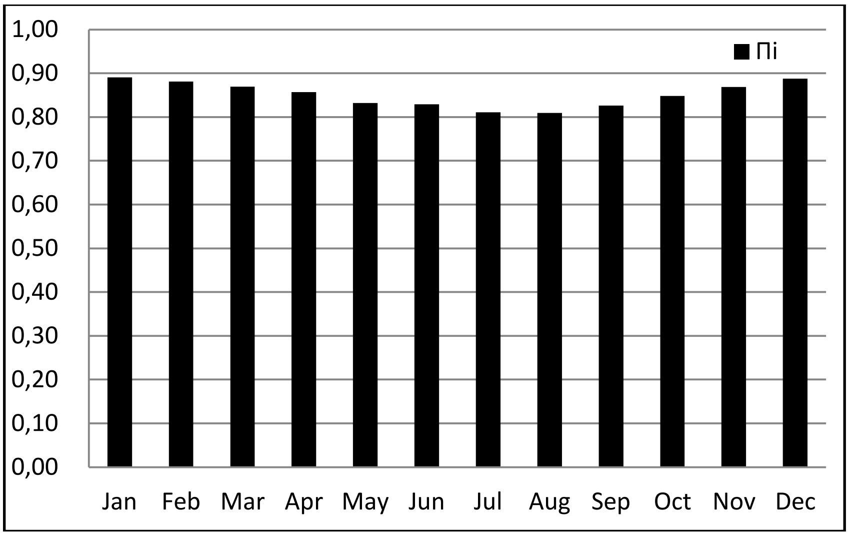
Graph 5d: The mean monthly daily temperature of the PV, T_{pv} [°C]



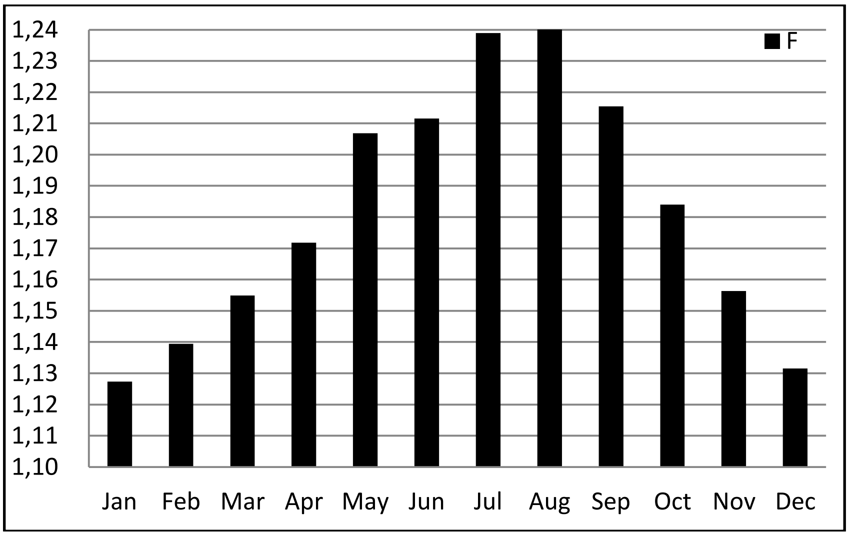
Graph 5e: Mean monthly values of the power transmission losses during the day operation of the PV system-loads, dP_m/P_m [%]



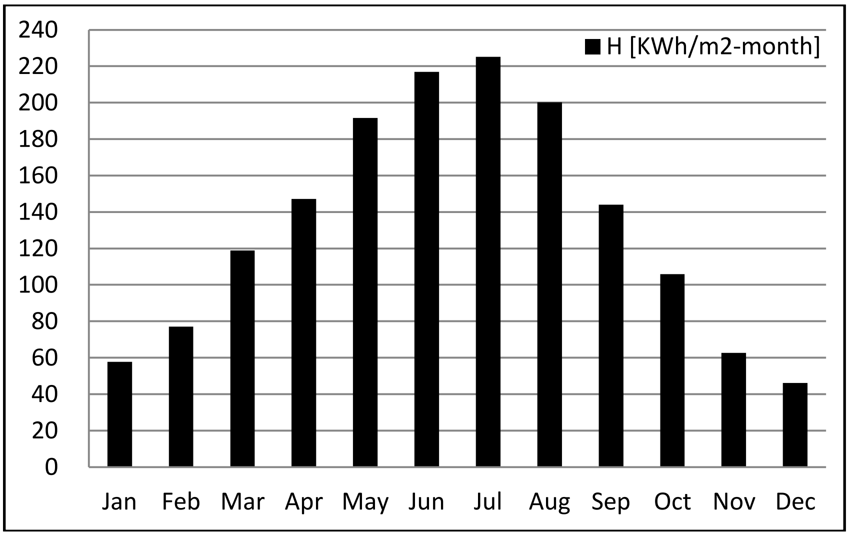
Graph 5f: Mean monthly values of the efficiency due to the temperature which developed on the surface of photovoltaics, Π_{temp}



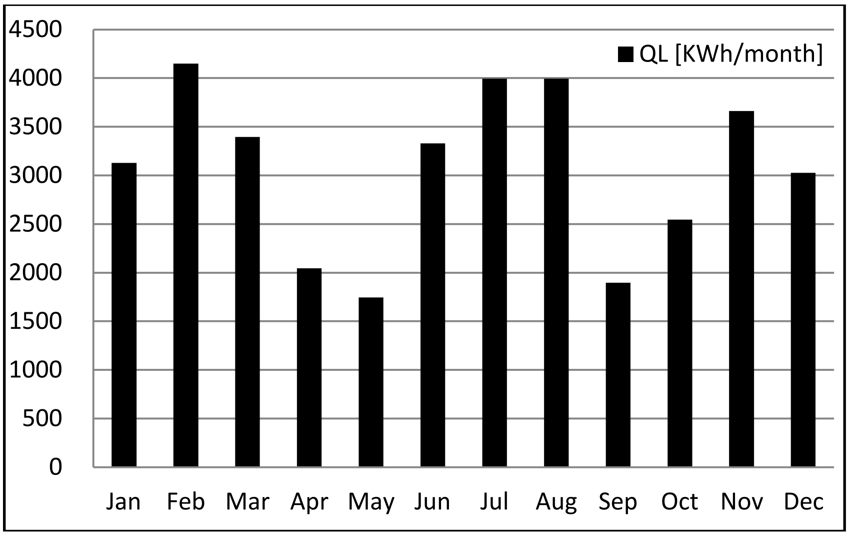
Graph 5g: Mean monthly values of the overall efficiency of the PV System, Π_i



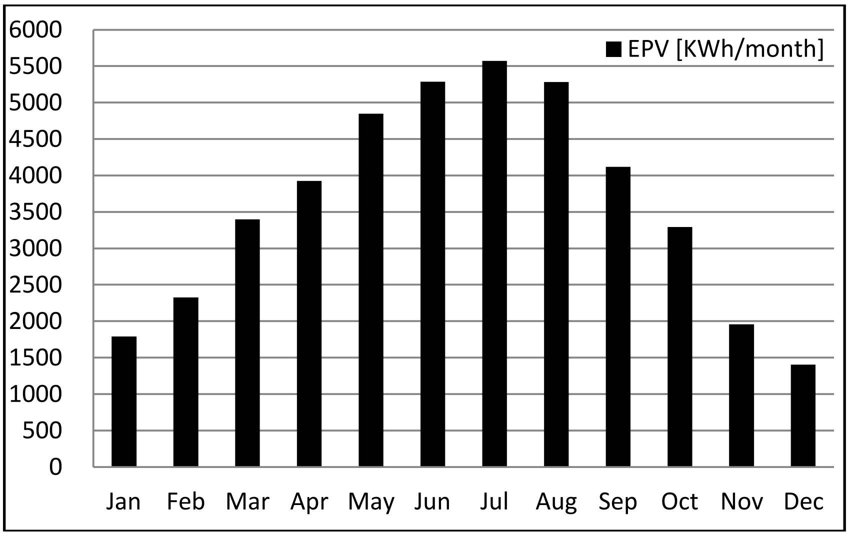
Graph 5h: Mean monthly values of the Correction Factor F - average values of the 20 years of operation of the PV System



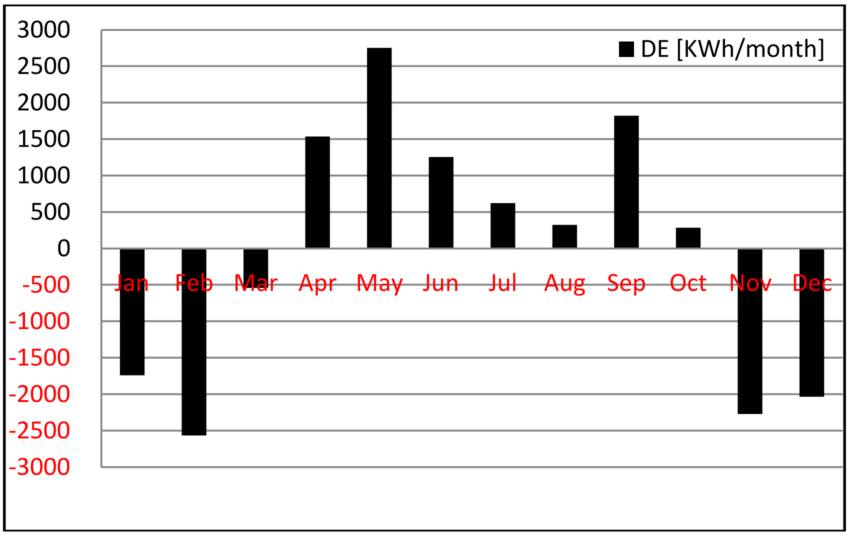
Graph 5i: Mean monthly values of solar radiation from daily data of 20 years from the database SODA (1985-2004), H [KWh/m^2-month]



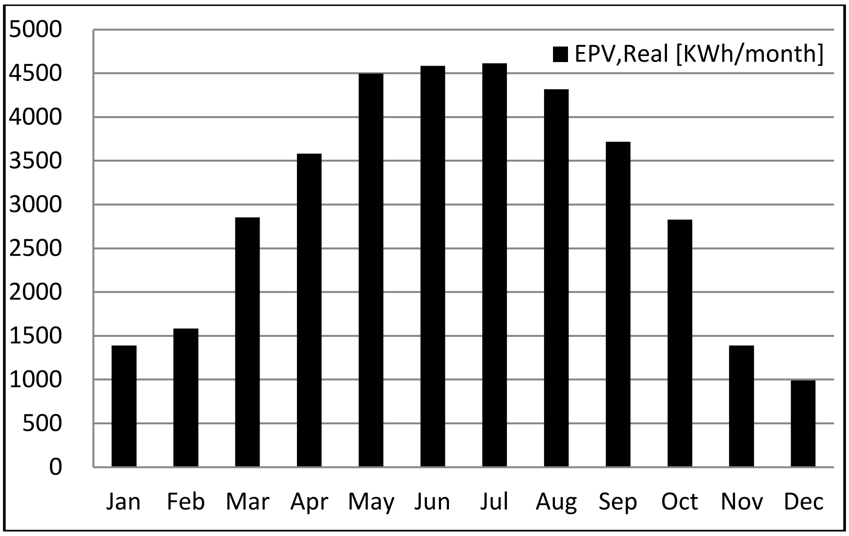
Graph 5j: Mean monthly values of the non-critical loads, Q_L [KWh/month]



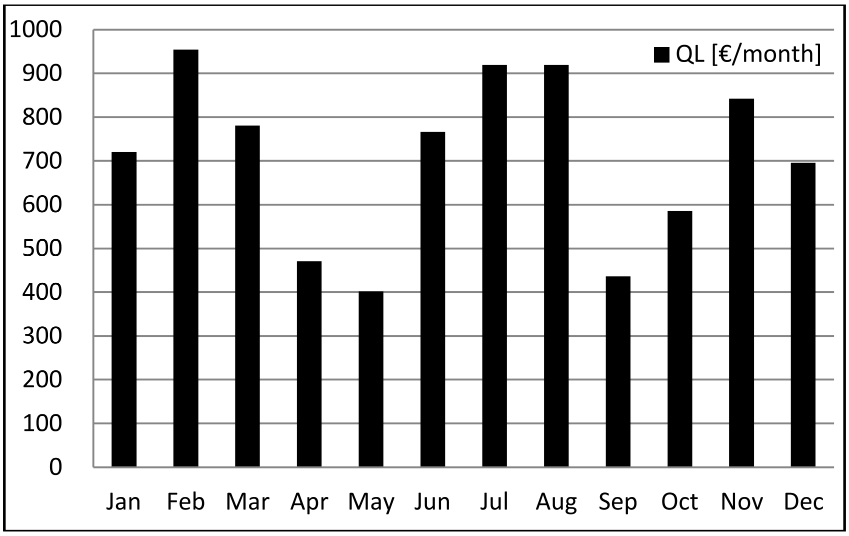
Graph 5k: Mean monthly values of the energy produced by the PV System with the same peak power (P_m), E_{PV} [KWh/month]



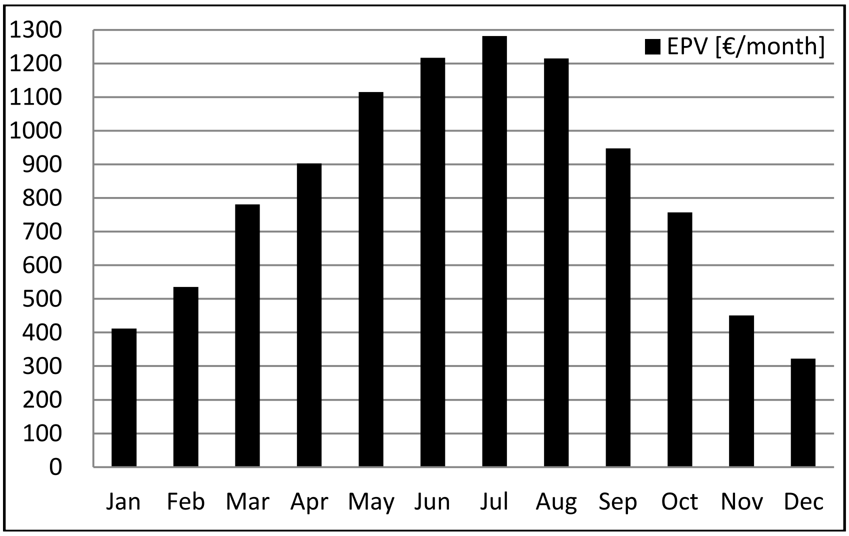
Graph 5l: Mean monthly values of the remaining amount of energy delivered by the PV System, after its consumption by the load, DE [KWh/month] - average values of the 20 years of operation of the PV System



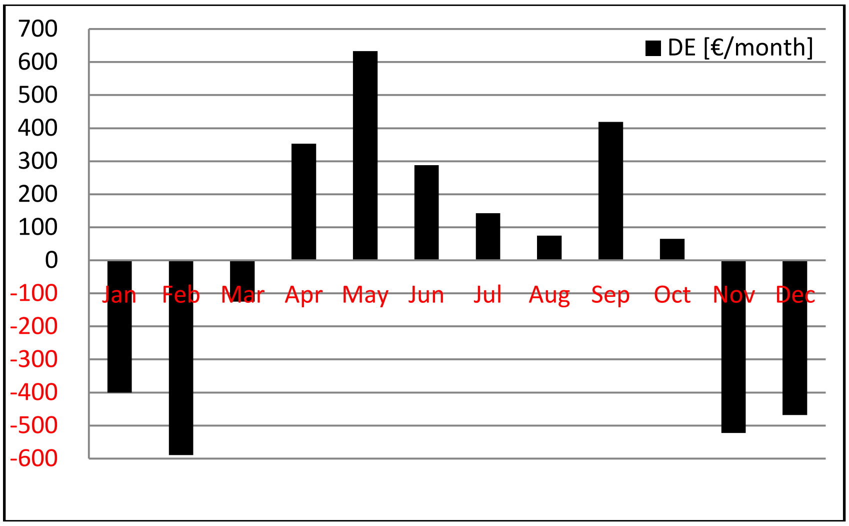
Graph 5m: Mean monthly values of the real energy delivered by the PV System after its degradation, $E_{PV,Real}$ [KWh/month] - average values of the 20 years of operation of the PV System



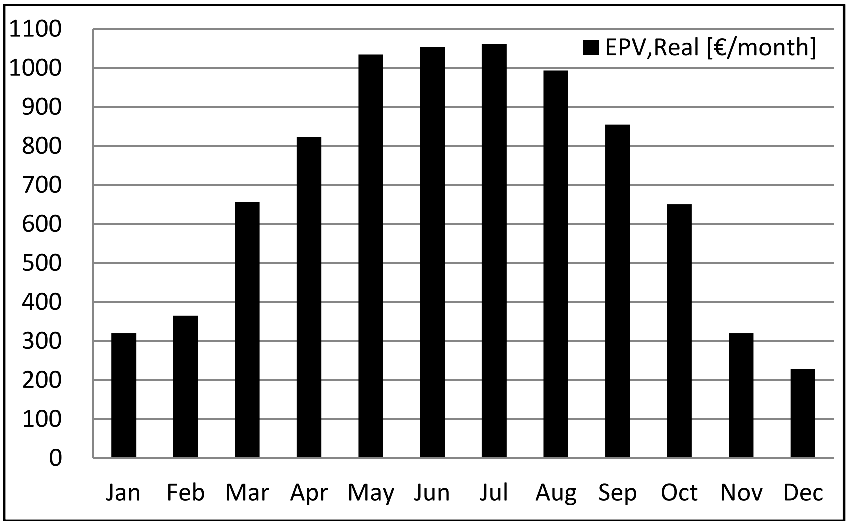
Graph 5n: Mean monthly values of the non-critical loads, Q_L [€/month]



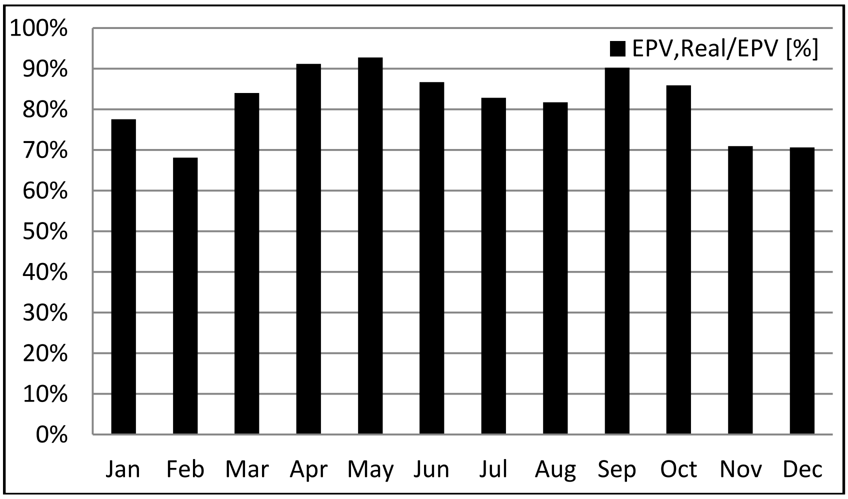
Graph 5o: Mean monthly values of the energy produced by the PV System with the same peak power (P_m), E_{PV} [€/month]



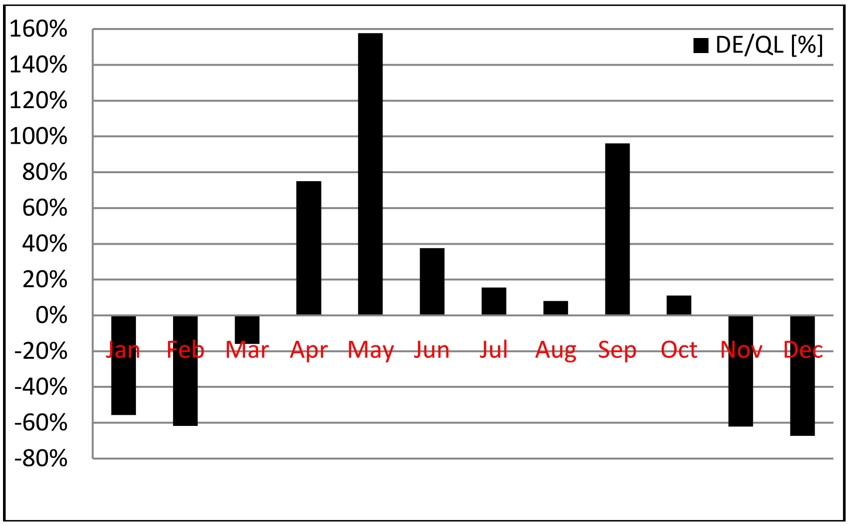
Graph 5p: Mean monthly values of the remaining amount of energy delivered by the PV System, after its consumption by the load, DE [€/month] - average values of the 20 years of operation of the PV System



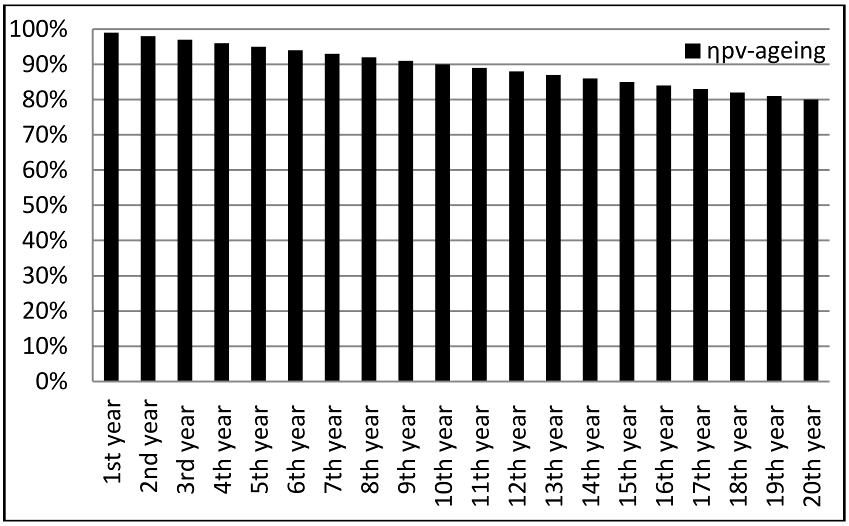
Graph 5q: Mean monthly values of the real energy delivered by the PV System after its degradation, $E_{PV,Real}$ [€/month] - average values of the 20 years of operation of the PV System



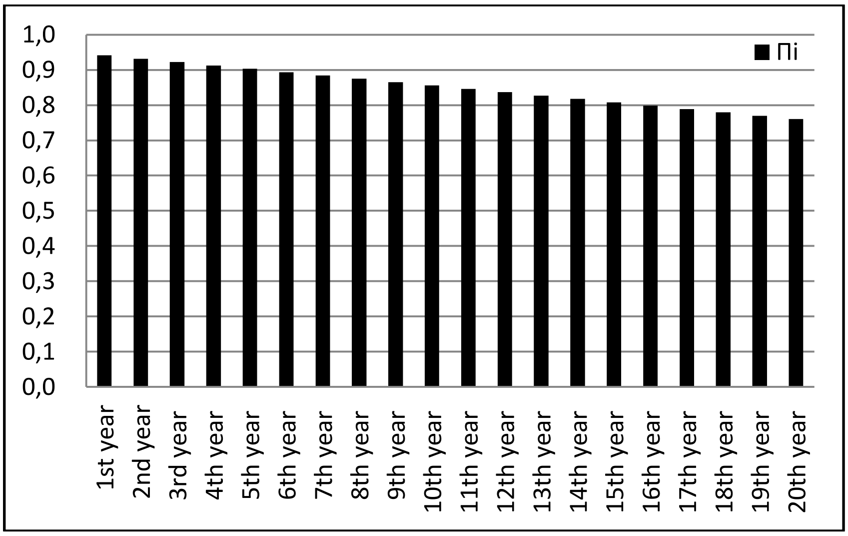
Graph 5r: Mean monthly values of the percentage of the real energy delivered by the PV System after its degradation, as to the maximum energy that could be delivered by the PV System, $E_{PV,Real}/E_{PV}$ [%] - average values of the 20 years of operation of the PV System



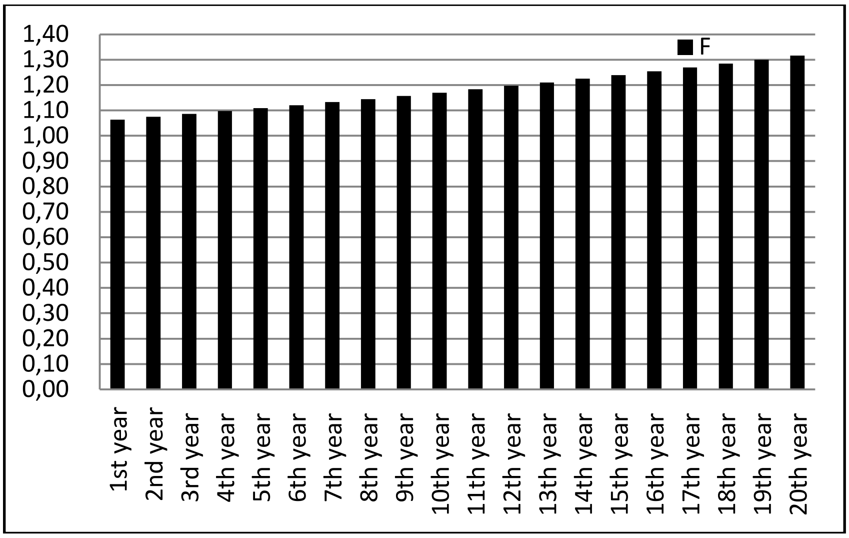
Graph 5s: Mean monthly values of the percentage of the excess or lack of electrical energy in relation to the electrical needs of the apartments, DE/Q_L [%] - average values of the 20 years of operation of the PV System



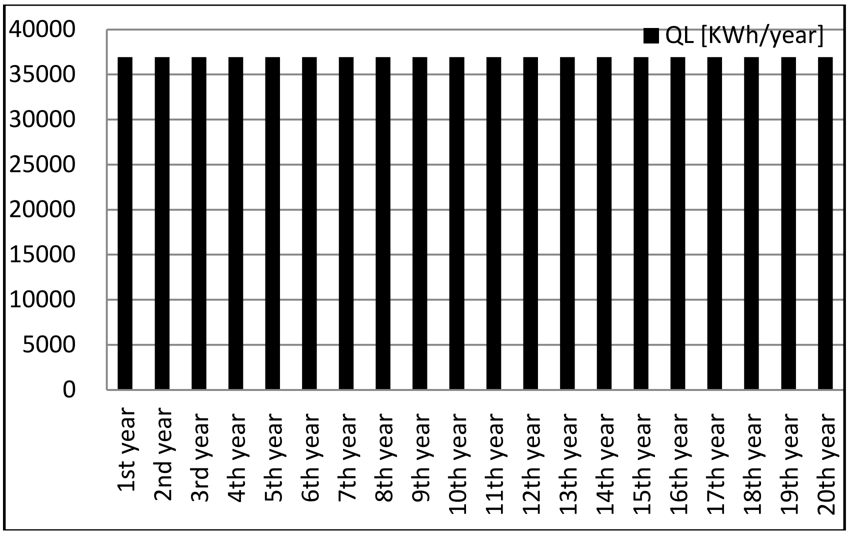
Graph 6a: Annual average values of the efficiency due to ageing of the photovoltaics, for the 20 years of operation of the PV System, $\eta_{pv\text{-}ageing}$ [%]



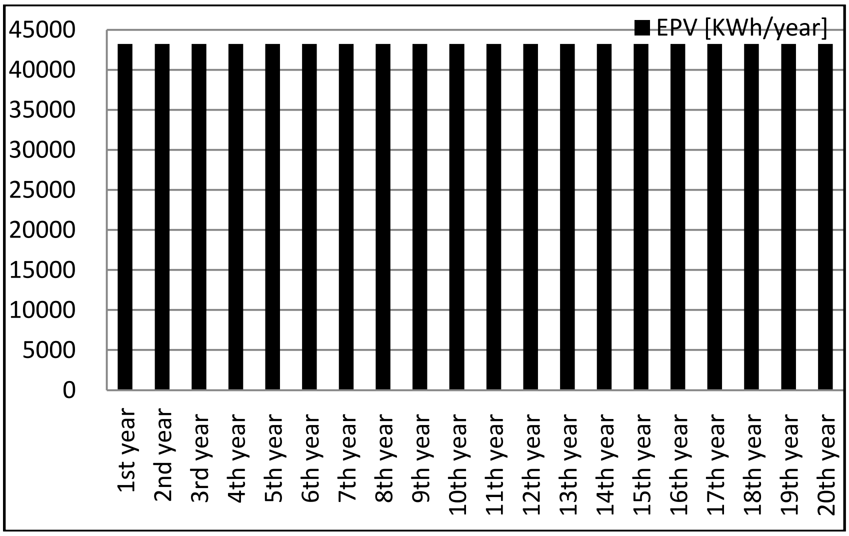
Graph 6b: Annual average values of the overall efficiency of the PV System, for the 20 years of operation of the PV System, Π_i



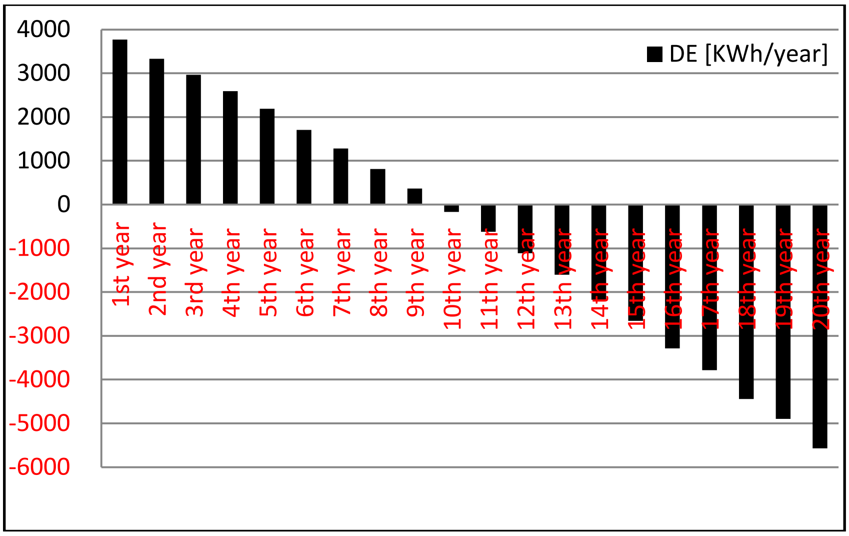
Graph 6c: Annual average values of the Correction Factor, for the 20 years of operation of the PV System, F



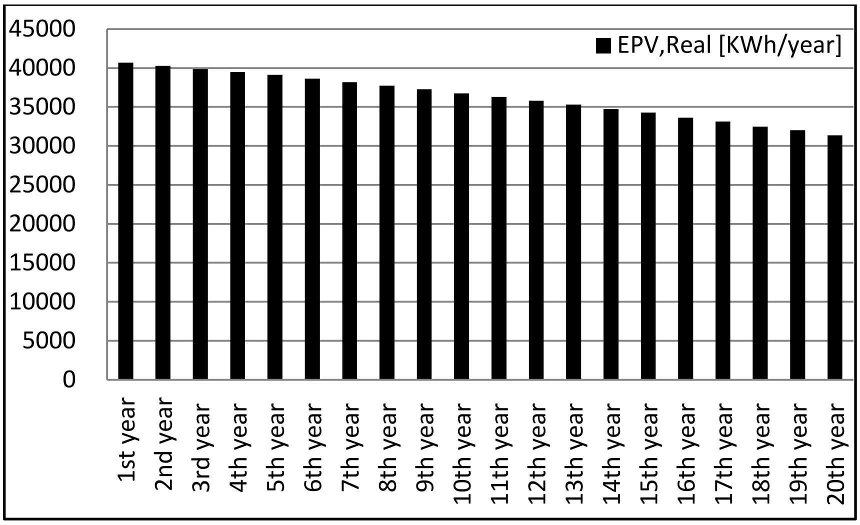
Graph 6d: Annual average values of the non-critical loads, for the 20 years of operation of the PV System, Q_L [KWh/year]



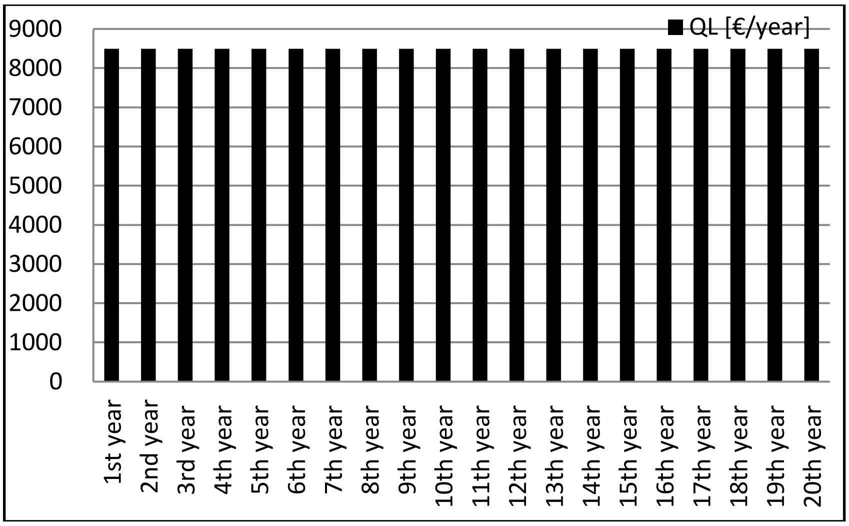
Graph 6e: Annual average values of the energy produced by the PV System with the same peak power (P_m), for the 20 years of operation of the PV System, E_{PV} [KWh/year]



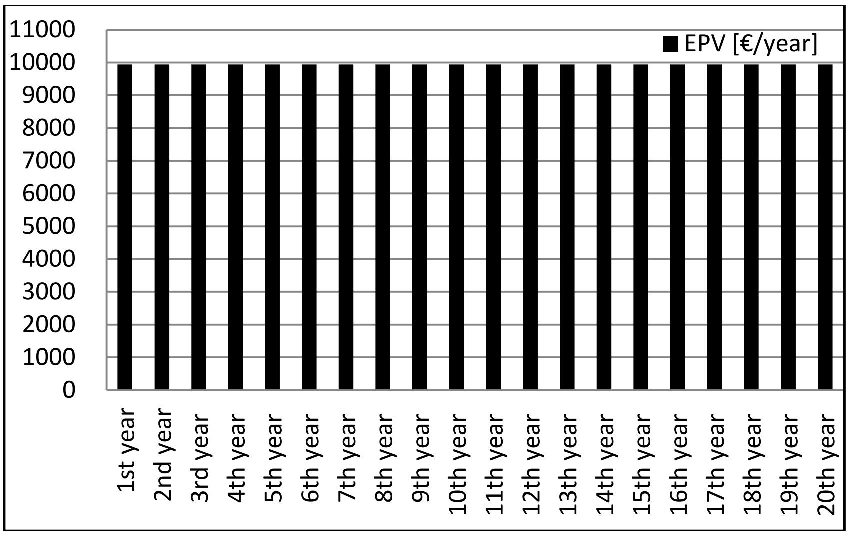
Graph 6f: Annual average values of the remaining amount of energy delivered by the PV System, after its consumption by the load, for the 20 years of operation of the PV System, DE [KWh/year]



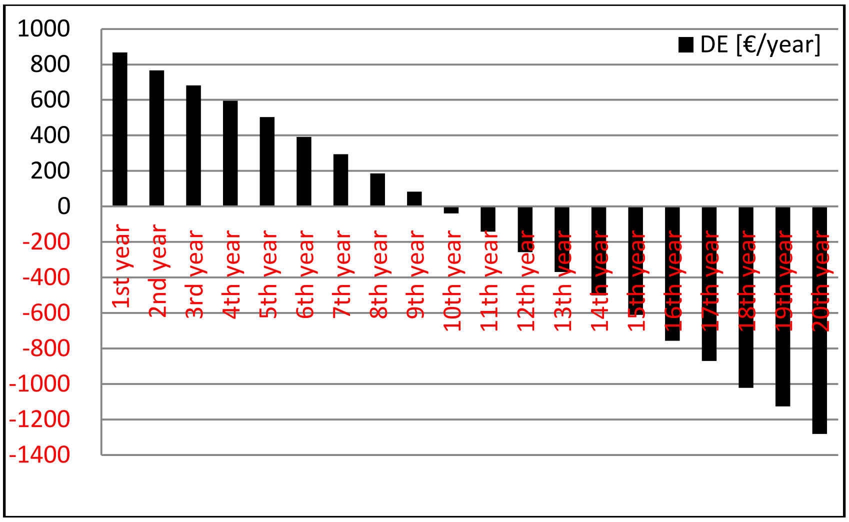
Graph 6g: Annual average values of the real energy delivered by the PV System after its degradation, for the 20 years of operation of the PV System, $E_{PV,Real}$ [KWh/year]



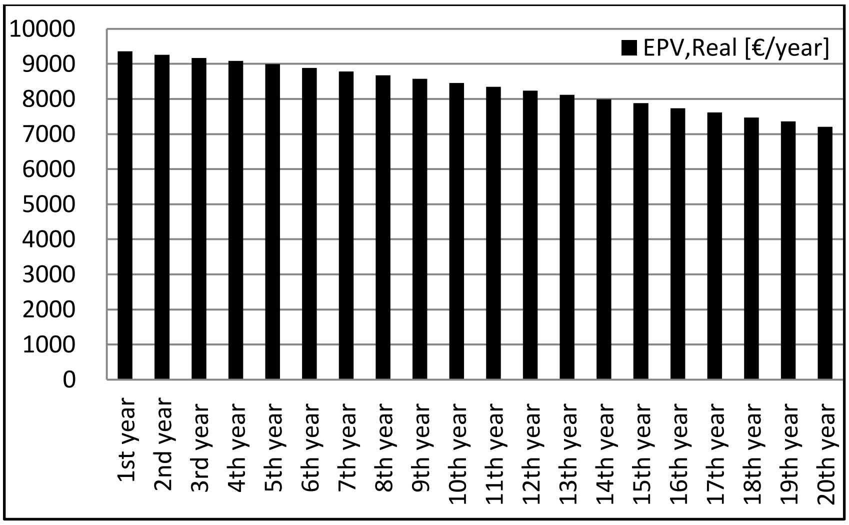
Graph 6h: Annual average values of the non-critical loads, for the 20 years of operation of the PV System, Q_L [€/year]



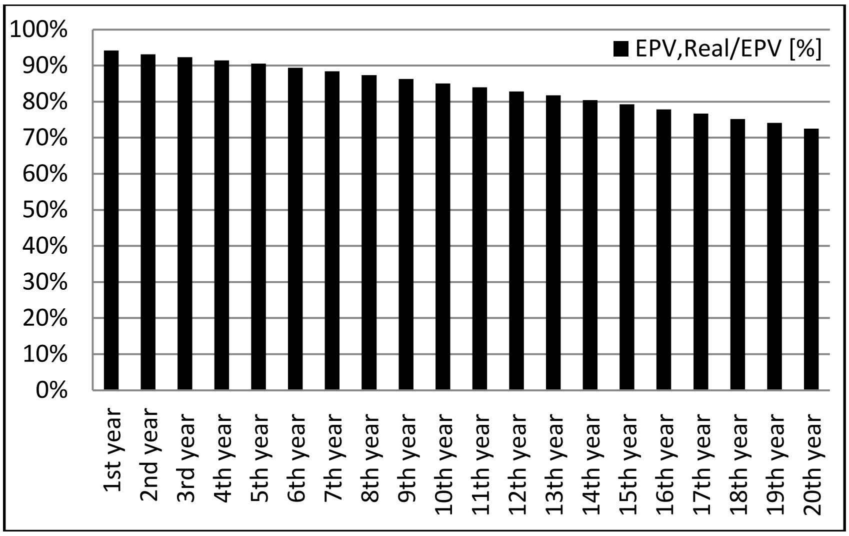
Graph 6i: Annual average values of the energy produced by the PV System with the same peak power (P_m), for the 20 years of operation of the PV System, E_{PV} [€/year]



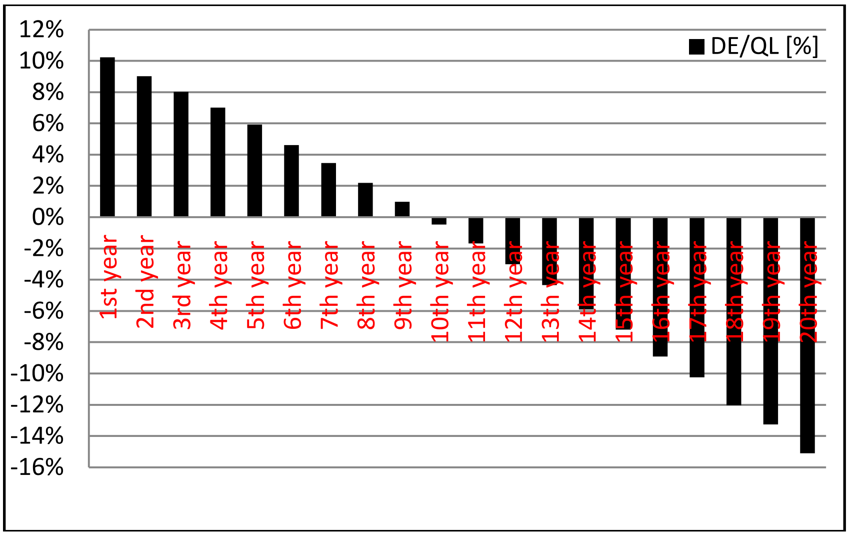
Graph 6j: Annual average values of the remaining amount of energy delivered by the PV System, after its consumption by the load, for the 20 years of operation of the PV System, DE [€/year]



Graph 6k: Annual average values of the real energy delivered by the PV System after its degradation, for the 20 years of operation of the PV System, $E_{PV,Real}$ [€/year]



Graph 6l: Annual average values of the percentage of the real energy delivered by the PV System after its degradation, as to the maximum energy that could be delivered by the PV System, for the 20 years of operation of the PV System, $E_{PV,Real}/E_{PV}$ [%]



Graph 6m: **Graph 5s**: Annual average values of the percentage of the excess or lack of electrical energy in relation to the electrical needs of the apartments, for the 20 years of operation of the PV System, DE/Q_L [%]

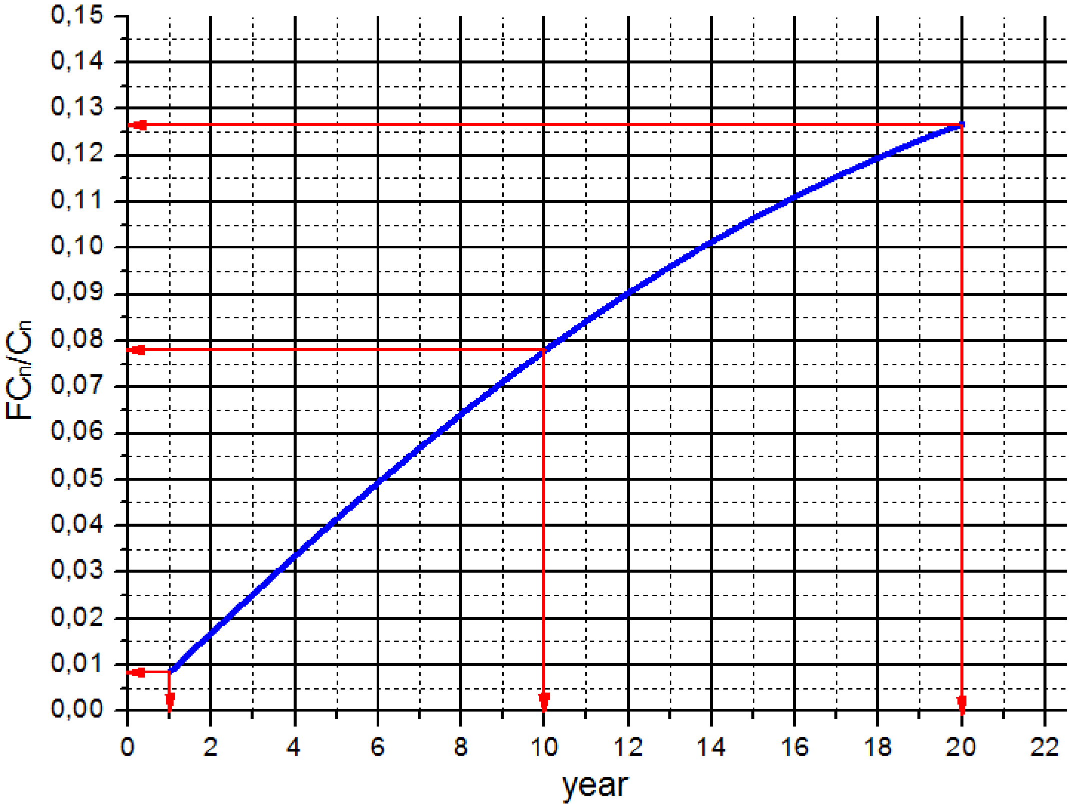
APPENDIX IV

Table 1: Presentation of the results of the investigation of the economic viability of establishment and operation of the PV plant

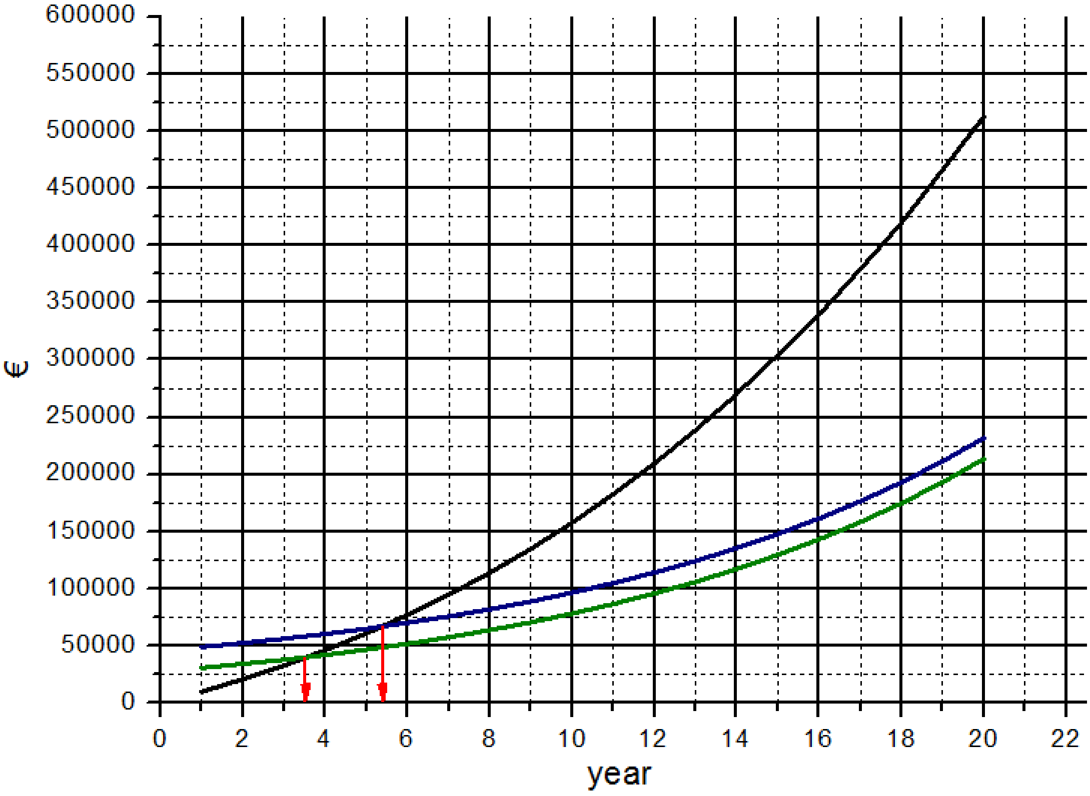
1	2	3	4	5	6	7	8	9	10	11	12	13
Year	R_o	R_n	IC_n	VC_n	FC_n	C_n	FC_n/C_n	C_n-γxIC_o	G_n	$G_n^{\sim}$	η*	η*$^{\sim}$
1	9359	9827	48546	0	416	48962	0,85%	30622	-39134	-37629	-0,854	-0,821
2	9258	20717	51512	0	888	52399	1,69%	34060	-31683	-29292	-0,691	-0,639
3	9173	32811	54775	0	1422	56196	2,53%	37856	-23385	-20789	-0,510	-0,453
4	9087	46192	58365	0	2024	60389	3,35%	42049	-14197	-12136	-0,310	-0,265
5	8994	60911	62317	0	2701	65017	4,15%	46678	-4106	-3375	-0,090	-0,074
6	8884	76952	66666	0	3461	70127	4,94%	51787	6825	5394	0,149	0,118
7	8785	94640	71455	0	4312	75767	5,69%	57427	18873	14342	0,412	0,313
8	8678	113899	76727	0	5264	81992	6,42%	63652	31907	23314	0,696	0,508
9	8575	134992	82534	0	6327	88861	7,12%	70521	46131	32411	1,006	0,707
10	8452	157623	88928	0	7512	96440	7,79%	78100	61183	41333	1,334	0,901
11	8349	182619	95972	0	8830	104802	8,43%	86463	77816	50548	1,697	1,102
12	8235	209545	103733	0	10296	114028	9,03%	95688	95517	59660	2,083	1,301
13	8122	238777	112284	0	11923	124206	9,60%	105866	114571	68808	2,499	1,501
14	7991	269810	121706	0	13728	135434	10,14%	117094	134376	77599	2,931	1,692
15	7881	304082	132092	0	15727	147819	10,64%	129479	156263	86767	3,408	1,892
16	7735	339583	143540	0	17940	161480	11,11%	143140	178103	95090	3,884	2,074
17	7621	379191	156161	0	20388	176549	11,55%	158209	202642	104031	4,420	2,269
18	7470	419863	170076	0	23093	193170	11,95%	174830	226693	111902	4,944	2,441
19	7365	466169	185421	0	26080	211502	12,33%	193162	254668	120876	5,554	2,636
20	7210	512532	202345	0	29376	231722	12,68%	213382	280811	128158	6,125	2,795

Table 2: Diachronic development of stable annual maintenance and operating costs of the installation

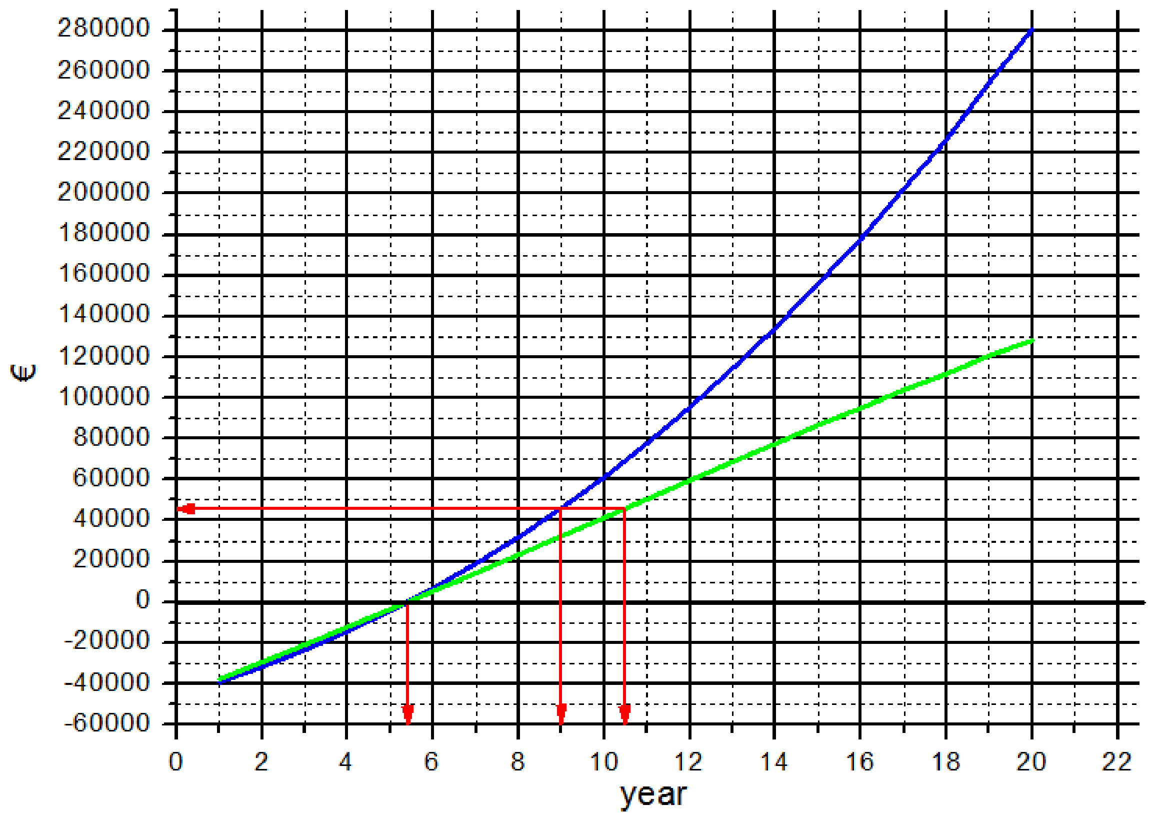
year	m_o [€/year]	δ [€/year]	m [€/year]	m_o [%]	δ [%]	m [%]
1	250,00	150,00	400,00	0,55%	0,33%	0,87%
2	252,50	150,00	402,50	0,55%	0,33%	0,88%
3	255,03	150,00	405,03	0,56%	0,33%	0,88%
4	257,58	150,00	407,58	0,56%	0,33%	0,89%
5	260,15	150,00	410,15	0,57%	0,33%	0,89%
6	262,75	150,00	412,75	0,57%	0,33%	0,90%
7	265,38	150,00	415,38	0,58%	0,33%	0,91%
8	268,03	150,00	418,03	0,58%	0,33%	0,91%
9	270,71	150,00	420,71	0,59%	0,33%	0,92%
10	273,42	150,00	423,42	0,60%	0,33%	0,92%
11	276,16	150,00	426,16	0,60%	0,33%	0,93%
12	278,92	150,00	428,92	0,61%	0,33%	0,94%
13	281,71	150,00	431,71	0,61%	0,33%	0,94%
14	284,52	150,00	434,52	0,62%	0,33%	0,95%
15	287,37	150,00	437,37	0,63%	0,33%	0,95%
16	290,24	150,00	440,24	0,63%	0,33%	0,96%
17	293,14	150,00	443,14	0,64%	0,33%	0,97%
18	296,08	150,00	446,08	0,65%	0,33%	0,97%
19	299,04	150,00	449,04	0,65%	0,33%	0,98%
20	302,03	150,00	452,03	0,66%	0,33%	0,99%



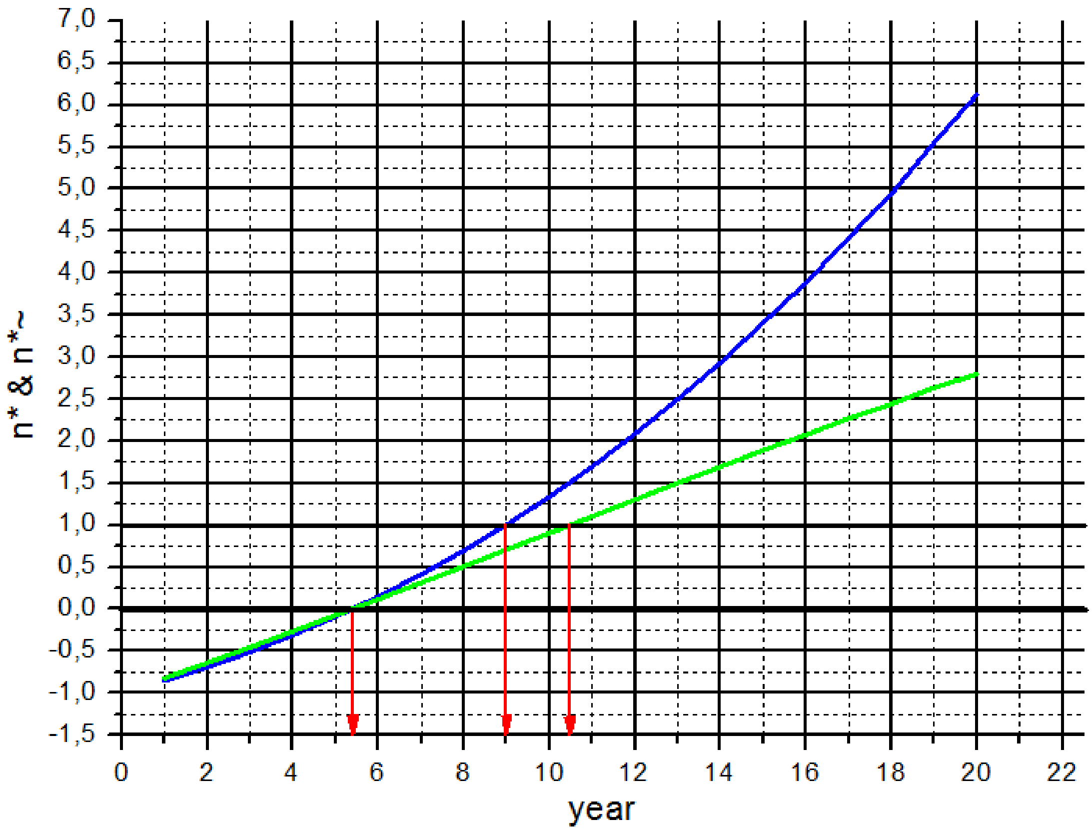
Graph 1: Diachronic alteration of the stable maintenance and operating costs of the investment as percentage of the total investment cost



Graph 2: Diachronic development of revenues of the investment ($R_n \rightarrow$ with black) and diachronic development of the investment cost with and without the participation of the government, ($C_n \rightarrow$ with blue) and ($C_n - c \cdot C_o \rightarrow$ with green) respectively



Graph 3: The diachronic change of the net profits of the investment (before taxes) at current (G_n → with blue) and constant prices ($G_n^{\sim}$ → with green) of inflation



Graph 4: The course of the economic efficiency of the investment for current (n^*→ with blue) and constant prices ($n^{*\sim}$ → with green) of inflation

APPENDIX V

At the following plans, are shown the floor plans of the building, i.e.:

1. The floor plan of the ground floor
2. The floor plan of the first floor
3. The floor plan of the attic