# Energy investigation on households with BIPV modules under Net Metering Scheme

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**Abstract:** In recent years many Renewable Energy Sources (RES) power plants have been connected to power networks throughout Europe, in order to meet the EU's objectives for sustainable energy supply. As far as low-voltage distribution networks are concerned, the grid-connected photovoltaic (PV) systems constitute the most important representative of RES, because these can be easily installed even in densely built-up areas where space problems are inevitable. In this context, small residential PV systems utilising BIPV modules are going to gain ground mainly at newly built or rebuilt building structures. That is because a BIPV module operates as a multi-functional building construction material; it generates energy and serves as part of the building envelope. This paper highlights the energy benefits of residential buildings in Southern Europe with BIPV modules under Net Metering Scheme. The energy benefits are reflected in monthly basis.

## 1. Introduction

Every building during its life cycle is associated with energy consumption. In accordance with studies that have compared the direct consumption (useful building operation), to that of the indirect consumption (construction and final demolition of the building), it turns out that the second one is extremely small compared to the energy consumed during the useful operating phase of buildings *(Sartori and Hestnes, 2007)*. The direct energy consumption of a building depends on many factors, the main of them being the climatic conditions, the kind of building use, the aging, the thermal transmittance of the building materials and the efficiency of heating/cooling systems installed *(Spyropoulos and Balaras, 2011; Asimakopoulos et al., 2012; Sfakianaki et al., 2011; Santamouris and Kolokotsa, 2013; Kapsalaki et al., 2012)*.

This paper highlights the energy benefits of residential buildings in Southern Europe with BIPV modules under Net Metering Scheme. Net Metering in Europe places consumers at the core of the energy policy, encouraging them to get involved in the energy transition, to benefit from PV technology to reduce their bills and participate actively in the market of electricity production. It is noteworthy in this context that the residential buildings account for 75% of the total stock in Europe, while 36% of the total estimated floor space is located in the South region of Europe *(Directive 2010/31/EU; Economidou, 2011)*.

Considering that a BIPV module operates as a multi-functional building construction material (it generates energy and serves as part of the building envelope), it is believed that BIPV modules are going to gain ground mainly on newly built or rebuilt residences. In more detail, BIPV modules provide not only economic benefits to building users (by reducing the electricity bills and substituting building elements), but also provide energy benefits to the electricity Distribution Network Operators and serve the EU objectives for sustainable renewable energy supply, contributing also in the reduction of greenhouse gas emissions.

Considering that there are significant differences between net metering programs around Europe, a short description of the key points of net metering in Greece is essential. The Greek net metering program for auto-producers is a regulatory framework under which the excess electricity injected into the grid can be used at a later time to offset consumption during times when their onsite renewable generation is absent or not sufficient. Offset of the PV energy output from consumption is considered on an annual cycle. Eligible applicants/investors are private persons and public or private legal entities. The program concerns fixed photovoltaic systems, while in case of residential buildings the PVs capacity should be less that the half of the contracted power capacity of the building and can never exceed the value of 20 kWp (*Tselepis, 2015*).

The results presented in the next sections stem from the installation of BIPV modules at a residential building at Pikermi-Athens. The BIPV modules which have been installed are based on an innovative encapsulation technology for solar cells (European project Bfirst "Building-integrated FIbre-Reinforced Solar Technology", *http://www.bfirst-fp7.eu/home/*). More precisely, the project aims to the design, development and demonstration of a portfolio of innovative photovoltaic products for building integration, based on cell encapsulation within fibre-reinforced composite materials. From a technological point of view such BIPV modules present advanced characteristics in terms of adaptability to non-planar building geometries, low weight and reduced stages in the manufacturing process, issues to which BIPV modules were lagging behind even in the recent past. The results presented next, stem from the participation of CRES and CUT in the EU funded project Bfirst "Building-Integrated, Fibre-Reinforced Solar Technology".

## 2. Building characteristics—data acquisition and utilization

The residential building under study occupies a total area of 140 m$^2$ and it is located at Pikermi 20 km from the centre of Athens. The residence is a low energy consumption building that is equipped with a ground heat geothermal Heat Pump (H.P.), which serves the heating and cooling demands of the building and the domestic hot water needs. The power demand of the household appliances is served via a three phase low voltage line.

In addition, the building features a PV system with BIPV modules. Considering that the contracted power capacity of the building is 25 kVA it is presumed that the peak power of the PV system (under Net Metering scheme) should not exceed the 12.5kVA. Additionally, the PV system should be compatible with the building's electric plan and thus the generated power should be injected into the grid through a three phase low voltage line. Furthermore, supposing that the main field of application of BIPV modules will be the densely built-up areas, where space problems are inevitable, it was decided to limit the total capacity of PVs at the significantly lower power level of 3.21kWp.

In more detail, the PV system composed of three subsystems: The first one is installed around two balconies with 765W peak power, the second one is installed as a façade on a vertical wall which faces the south-east with 2205W peak power, and the last is installed as shading elements that also face south-east with 240W peak power. The abovementioned subsystems are illustrated in Fig. 1-3.


Fig. 1 Balconies PV Subsystem


Fig. 2 Facade PV Subsystem


Fig. 3 Shadings PV Subsystem

The selection of slopes and orientations of subsystems was not based on maximizing annual production, but to demonstrate various options for the integration of BIPVs into buildings. The connection of all PV subsystem to the low voltage electricity network was preferred to implement with the use of single phase micro-inverters and not a string technology inverter. The benefits of this approach are not only to avoid power losses due to mismatch between PV modules with different orientation and/or inclination, but also the optimal matching of PV modules characteristics with the individual micro-inverters of appropriate power *(Kjaer, 2005)*. Finally, Fig. 4 shows the single line electrical diagram (SLD) of the PV system.

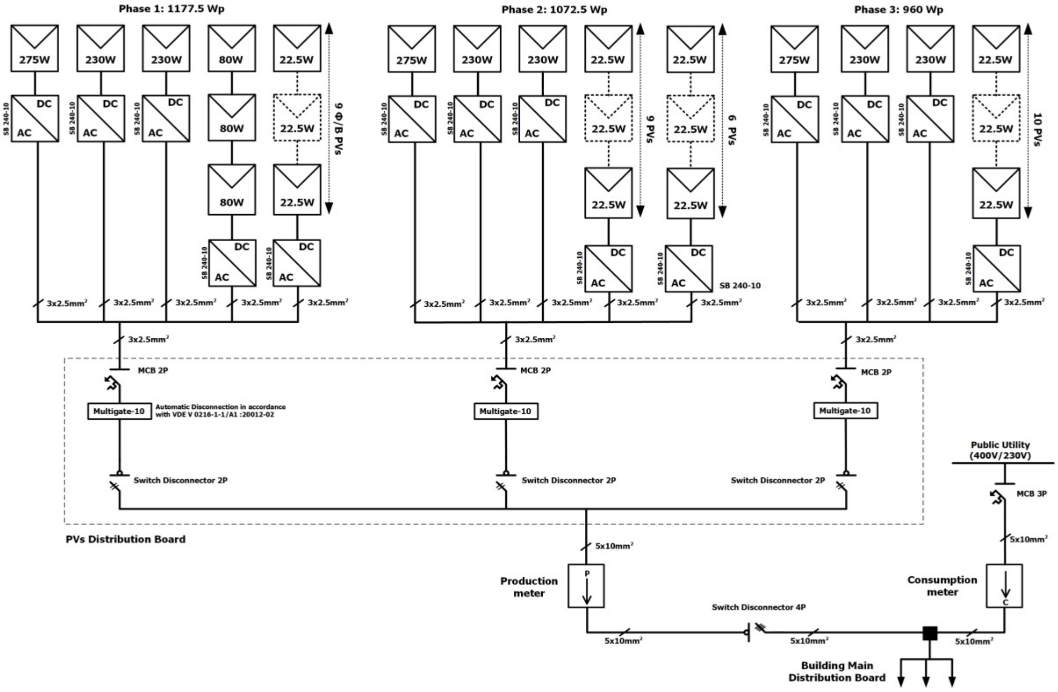


Fig. 4 Single line electrical diagram of the PV system

In order to correlate the electricity consumption of the household appliances to the PV energy production and the ambient conditions, power analyzers and sensors were installed at selected places of the building. Beyond energy benefits, the impact of the façade PV subsystem on the internal comfort of the building is also considered. Fig. 5 shows the position of the aforementioned power analyzers and the sensors that record the external and internal environmental conditions of the building.

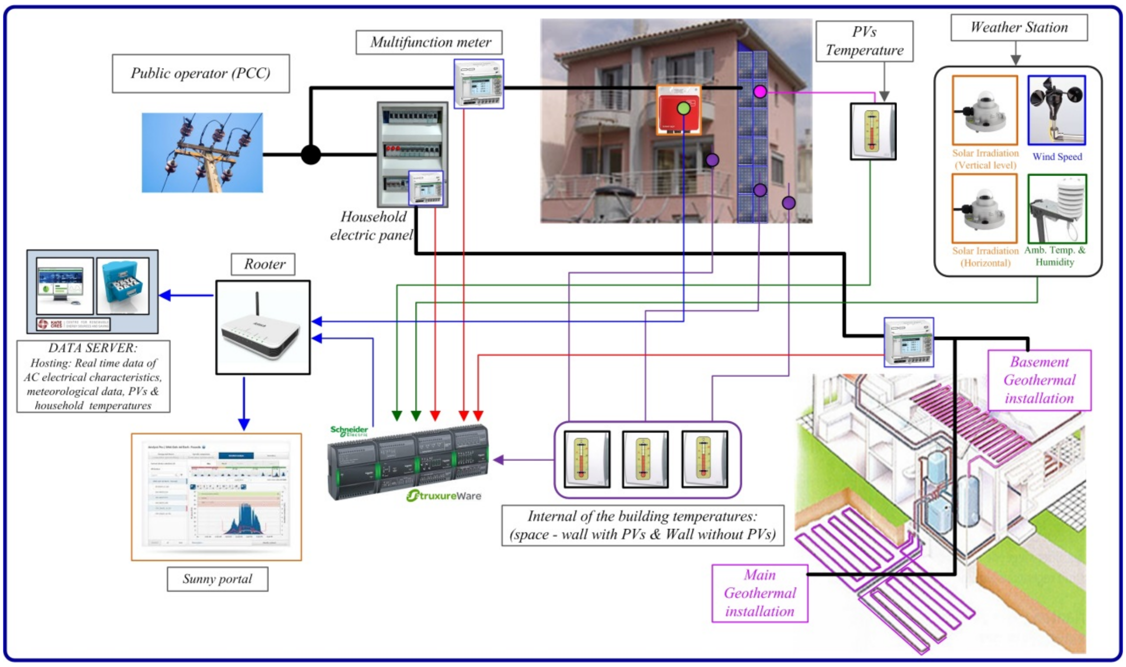
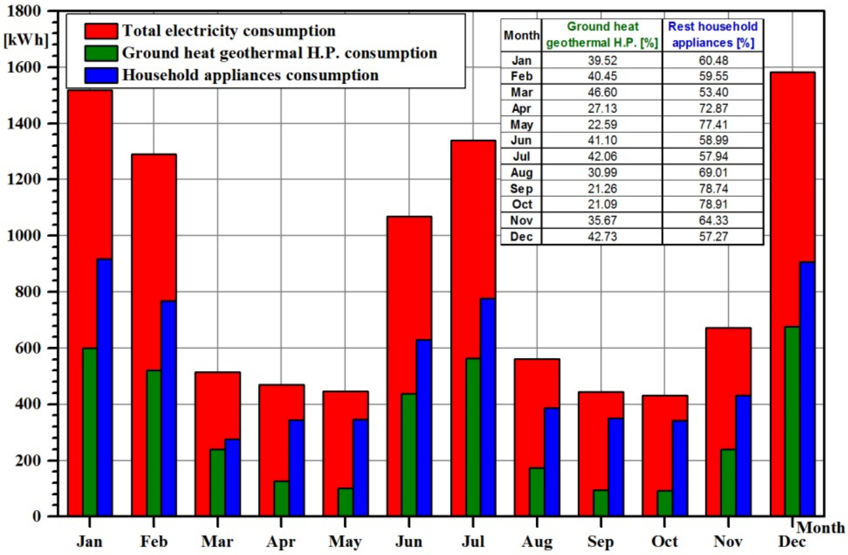


Fig. 5 Plan showing the power analyzers and sensors used to monitor power flows, and the internal and external environmental conditions of the building

Data storage together with data processing capability is accomplished in real time via the internet digital transmission platform “SmartStruxure TM series” of Schneider Electric. The data are stored as ten minute average values, a resolution which is satisfactory for a sufficient correlation between the energy production, the energy demand and the environmental conditions. A full data series before the installation of the PV system was recorded as a reference period (2016). Then, after incorporating the PV system, a full data series will record for the year 2017. It is important to note, that although the electricity consumption of the building, the ambient conditions and building internal comfort have been monitored for more than a year, the energy production from PVs refers to a less than a month period. Thus, in order to investigate the energy benefits on an annual basis, the photovoltaic generation is estimated via TRNSYS and PV Syst simulation software packages.

## 3. Evaluation of the electricity consumption and calculation of the electricity production

Initially, this section outlines the conclusions drawn after the analysis of the time series of electric power consumption for the base year 2016. On the basis of energy density indicators per unit area, the total electricity consumption for the baseline year 2016 was 73.86 kWh/m$^2$/year, of which 37.4% was spent on the electricity powered ground heat geothermal heat pump and the remaining 63,6% in household appliances. Fig. 6 shows the allocation of the total electricity consumption on a monthly basis for the baseline year. The total electric consumption is divided into two components: a) Ground heat geothermal H.P. consumption and b) the consumption of the rest household appliances.



| Month | Ground heat geothermal H.P. [%] | Rest household appliances [%] |
|---|---|---|
| Jan | 39.52 | 60.48 |
| Feb | 40.45 | 59.55 |
| Mar | 46.60 | 53.40 |
| Apr | 27.13 | 72.87 |
| May | 22.59 | 77.41 |
| Jun | 41.10 | 58.99 |
| Jul | 42.06 | 57.94 |
| Aug | 30.99 | 69.01 |
| Sep | 21.26 | 78.74 |
| Oct | 21.09 | 78.91 |
| Nov | 35.67 | 64.33 |
| Dec | 42.73 | 57.27 |

Fig. 6 Allocation of the electricity consumption on a monthly basis for the baseline year

According to the data presented in Fig. 6, the most energy intensive months of year 2016 were January, February, June July and December, where the net energy transactions with the electric network exceed at least the value of 7.63 kWh/m$^2$ for each month. Furthermore it is evident from the study of the same figure that building's electricity consumption has strong seasonal trends as a consequence of Southern Europe climatic characteristics (limited operation of heating/cooling system in spring and autumn due to mild weather).

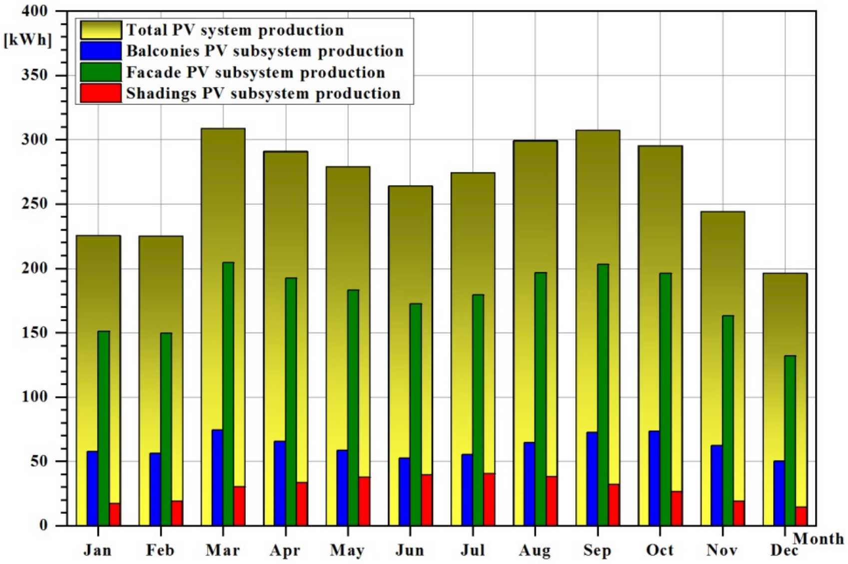


Fig. 7 Allocation of BIPVs production on a monthly basis for the baseline year

Considering that the PV system was connected to the low voltage electricity grid in the middle of January 2017, it was decided to estimate the produced PV energy for the base year 2016. Thus, all three PV subsystems were simulated with the use of TRNSYS and PV Syst simulation software packages. In both cases the recorded ambient data, from the installed weather station, were imported to the developed models. Therefore a direct comparison between the estimated BIPVs production and the real consumption of the residential building was made possible for one complete year. The abovementioned simulation results are reflected in Fig. 7. In specific terms, Fig. 7 depicts the allocation of energy production of all three PV subsystems on a monthly basis for the baseline year. On the basis of energy density indicators per unit area, the total electricity production for the baseline year 2016 is calculated to be 22.9 kWh/m$^2$/year. Furthermore, according to the data presented in Fig. 7 the relative production index of the total PV system is calculated to be 1MW$_{el}$/kW$_p$.

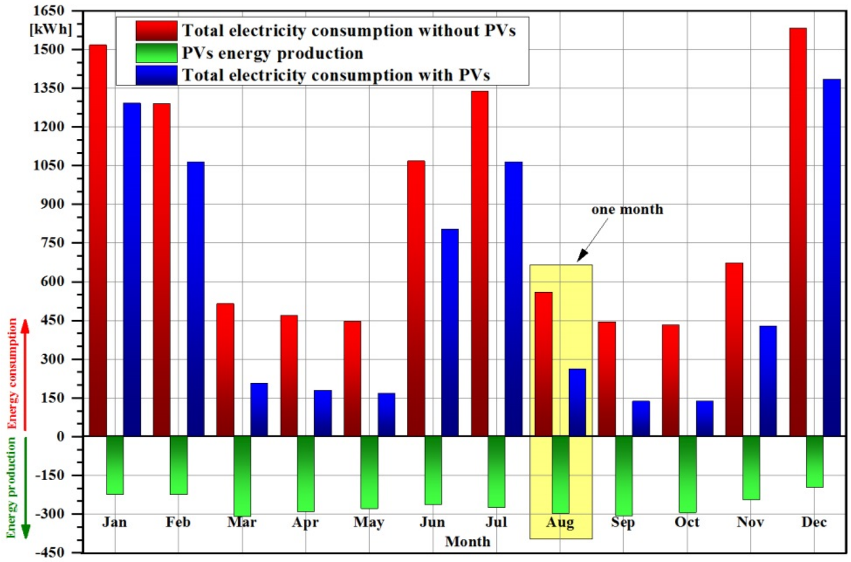


Fig. 8 Building total electricity consumption before and after the installation of the BIPV system on a monthly basis

Consequently, Fig. 8 illustrates the building total electricity consumption before (red color real–measurements) and after (blue color–simulation results) the installation of the BIPV system, as well as PVs production (green color–simulation results) on a monthly basis. Positive values reveal energy consumption, while negative values reveal energy production from the BIPV system. Furthermore, Table 1 summarizes on a monthly basis the reduction of residence’s electricity consumption after the installation of the BIPV system

Table 1: Percentage reduction of residence’s energy consumption after the installation of the proposed BIPBV system

| **Month** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sept** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduction of residence’s consumption [%] | 14.85 | 17.44 | 59.95 | 61.85 | 62.41 | 24.72 | 20.49 | 53.39 | 69.15 | 68.27 | 36.34 | 12.41 |

The influence of the proposed BIPV system to the buildings’ power exchange profile in smaller time scales was not considered, since the Greek Net Metering program does not contain any incentive to maximize the rate of energy self-consumption (in order to reduce buildings’ power exchange with the electrical grid). In other words, under the Greek net-metering scheme, consumers use the grid as a backup system for their excess power production.

## 4. Conclusions

Considering that in the Greek Net Metering program the electricity offsetting is carried out on an annual basis and any energy surplus after the running year is not compensated, there is no reason for the annual energy production by the photovoltaic system to exceed the total annual consumption of the consumer. Indeed the proposed BIPV system reduces the annual electricity consumption of the residence of almost 31% compared to the former situation, giving considerable economic benefits to building owners.

In the context of innovative electricity network architectures (such as micro-grids and smart-grids), Net Metering schemes have to be considered in combination with flexibility measures in order to maximize the self-consumption of the buildings. Flexibility can be realized through two main sets of measures: i) demand-side response through automated control of loads and ii) energy storage, including thermal and electricity storage. Such measures facilitate a high integration of variable renewable energy systems to the power system.

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