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# Solar Energy Systems Potential and Using PV Panels for Achieving Net Zero Energy Residential Buildings

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## ABSTRACT

Solar energy systems are currently the most widely installed renewable energy systems in the building sector in an effort to reduce the energy consumption of buildings. This paper investigates solar potential regarding photovoltaic and solar thermal utilization in typical residential buildings in order to identify their impact towards Net Zero Energy Buildings (NZEB). Different options regarding the installed capacity of photovoltaics and solar combi systems in various locations and climatic conditions are evaluated from a technical as well as from an economic point of view. The study starts with the analysis of the current situation of both the existing buildings and the energy sector in Egypt and Greece, analyzing the energy consumption patterns and the inefficiencies leading to these patterns, then defining the nZEB concept to familiarize the reader with its different aspects. The empirical part of the study utilizes simulation to validate the proposed guideline by applying it on an already existing residential building. The detailed steps of converting an already existing residential building to an nZEB is the final outcome of the research.

**Keywords**: Zero energy buildings, Solar heating systems, Photovoltaics, Residential buildings

## 1. INTRODUCTION

The building sector represents one of the biggest energy consumers in the European Union (EU), accounting for more than 40% of final energy consumption (Environment Agency, 2010). To combat that, the EU implemented a series of directives that promote the use of energy alternatives for buildings, used primarily for electricity, heating, cooling and the provision of hot water, starting with Directive 2009/28/EC (2009/28/EC, 2009) which implied that all member states should increase the use of renewable energy sources along with energy efficiency and savings by 20% until 2020. Shortly after, EU passed Directive 2010/31/EC (2010/31/EC, 2010) defining minimum rules on the performance of buildings and introducing energy certificates, taking into account the external climatic conditions and defining the NZEB. To qualify as a NZEB, a building has to exhibit a very high energy performance and to cover the amount of energy required to a very significant extent from renewable sources that are produced on-site or nearby. Moreover, after 2018 all newly constructed buildings that were either occupied or owned by public authorities must qualify as NZEB, with all other new buildings following suit from 2020.

Of the various renewable energy systems that can be installed in the building sector in order to cover energy requirements (electrical and thermal loads), solar energy systems are currently the most widely used, mostly in the form of solar thermal and photovoltaic systems. Especially for the southern countries of the EU, which typically have high annual solar radiation and temperatures, solar energy systems are already a viable alternative to fossil energy systems and are expected to become even more efficient and cost-competitive in the future (Ecofys, 2013). Most EU countries of the region enjoy high numbers of new installations annually both in the form of Domestic Solar Hot Water Systems (DSHWS) and of grid connected photovoltaic systems, while the biggest potential is expected for renewable combi systems that generate heat for space heating purposes in winter, cooling through air-conditioning systems in summer and domestic hot water throughout the year.

The increasing energy consumption rates and the accompanied greenhouse gas emissions are considered one of the world's greatest concerns recently. The total energy sold in Egypt for the year 2014 reached 120 terra watt hour with an annual average growth rate of 5.2%. The building sector alone -including all building types- contributes with 40% of total energy consumption and one third of greenhouse gas emissions globally, and the numbers are even higher in Egypt, reaching 51% of total energy sold in 2014. Mentioning the harmful emissions in Egypt, the CO2 per capita reached 3.88 ton/year in the latest statistics provided by CAPMAS for the year 2011 rising from 2.93 ton/year in 2008. For this reason the building sector represents a large potential for significantly reducing the energy demand and the harmful emissions.

## 2. NET ZERO-ENERGY BUILDINGS

A clear definition of the nZEBs is: "A zero energy building refers to a building with a net energy consumption of zero over a typical year. It implies that the energy demand for heat and electrical power is reduced, and this reduced demand is met on an annual basis from renewable energy supply".

To sum up the characteristics of nZEBs as stated by the EPBD recast:

- Having a very high energy performance.

- Energy demand should be reduced to nearly zero or very low.

- Energy requirements should be fulfilled to a very significant extent by renewable resources.

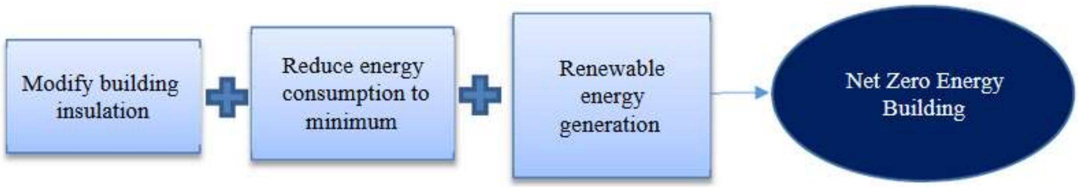


**Fig.1:** Aspects of reaching net zero-energy building

Buildings in Egypt are characterized by low levels of insulation from what leads to a very poor thermal performance and low indoor air quality. A survey conducted in 2012revealed that the building envelopes of the surveyed buildings -1500 apartments- were not airtight, all the openings were single glazed, walls were not insulated and no shading treatment was provided. To compensate for this technical problem, 80% of the apartments installed at least one air conditioner unit, and this leads to the peak electric loads that causes failure and complete shutdown of the grid, as experienced recently in Egypt. It is worth saying that the final survey findings showed that the use of air-conditioners raised the annual electricity bill by 44% to 57% in Cairo.

The residential sector in Greece was responsible for 29.44% of the total final energy consumption in 2012 (YPEKA, 2014). According to a recent survey (Statistics Authority, 2011), every household in the country consumes, on average, 10.2 MWh of thermal energy, for space heating, hot water production and cooking and 3.75 MWh of electricity for the various electrical appliances. As Directive 2010/31/EC has been integrated in the Greek regulatory framework, energy demands for heating are expected to decline from more than 100 kWh/m2,a to as low as 15 kWh/m2,a (Asimakopoulos et al., June 2012). According to the latest census, which was carried out in 2011, approximately 86% of all Greek residences have an area of up to 120 m2 while the average household, not taking into account single member households, consists of 3.5 persons (Statistics Authority, 2011).

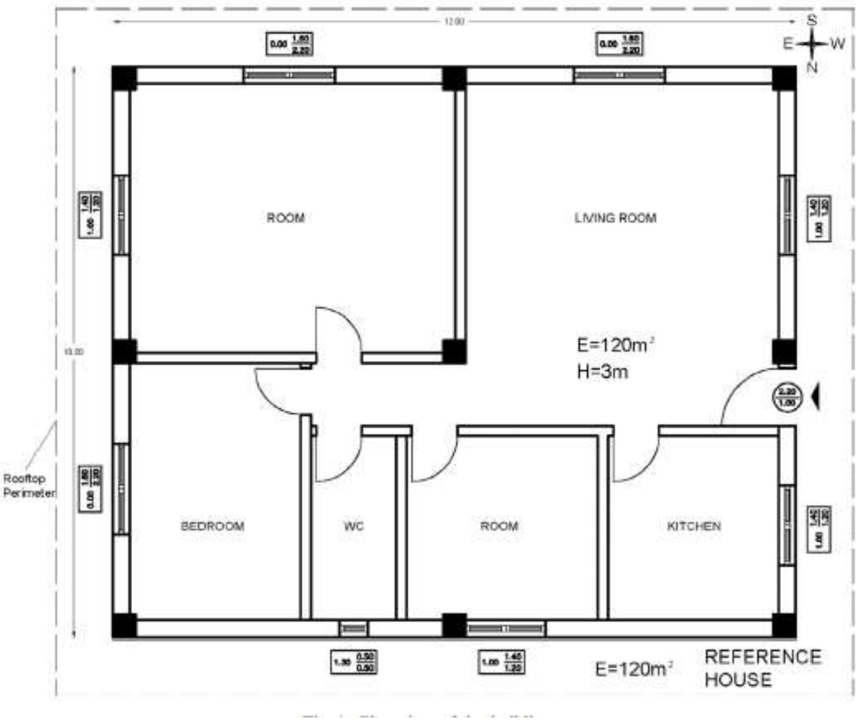


**Fig. 2.** Plan view of the building.

The Greek legislation scheme (KENAK), divides Greece into four climatic zones (A, B, C and D) thus, depending on the geographical location of the building different rules apply. In order to take into account for all the climatic zones, the analysis was conducted for the four larger (in population) cities as representative of each zone (Fig. 2), namely:

1- Zone A: (600–1100 Heating degree days) Heracleion (35.20°N, 25.08°E),

2- Zone B: (1101–1600 Heating degree days) Athens (37.50°N, 23.45°E) ,

3- Zone C: (1601–2200 Heating degree days) Thessaloniki (40.30°N, 22.58°E) and

4- Zone D: (2201–2620 Heating degree days) Florina (40.60°N, 21.26°E).

As solar thermal coverage we define the ratio of the useful energy provided by the solar thermal system divided by the total thermal load (Duffie and Beckman, 2006). On regional, national and international levels, energy policy is considering energy efficiency in buildings as a future target for the building design. This is why Zero-Energy Building design is recently taking a leading role in all the architecture, the architectural engineering, and the building physics sectors and having a significant importance among researchers on these fields. The European Energy Performance of Buildings Directive (EPBD) has published a recast on 2010 that defines some of its goals including that by 31 December 2020 all new buildings must be nearly zero-energy buildings (nZEB) in the Member States. Also the US Department of Energy (DOE) has proposed ‘marketable Zero-Energy Homes in 2020’ as a strategic goal to be achieved. Following the same pattern, the Solar Heating and Cooling Program (SHC) of the International

Energy Agency (IEA) -that has 20 member countries from all over the world- approved the Task 40 (Towards Net Zero Energy Solar Buildings) in 2008.

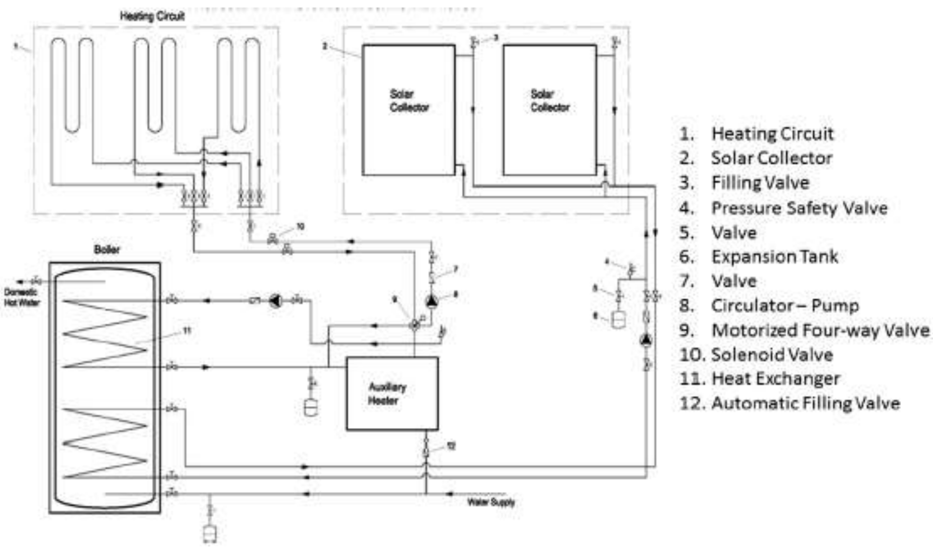


**Fig. 3.** Schematic of the solar heating system.

## 3. THERMAL AND ELECTRICAL LOADS OF THE BUILDING

For the computation of all the thermal loads of the buildings, the TEE-KENAK software, version 1.29.1.19, (software v1.29.1.19_20_05_12, 2012), which is a software that complies with the EN 13790 methodology was used. The methodology covers heating, cooling, hot water for all buildings and lighting for commercial buildings and it was used for computing the heating and cooling energy loads of the building in all cases. Although it is not a dynamic simulation tool like TRNSYS, it can be used with acceptable results (Wang et al., 2012; Tronchin and Fabbri, 2008).

The computed heating loads were then, converted into fuel oil and natural gas consumption assuming a:

- 90 % fuel oil boiler efficiency.

- 95% natural gas boiler efficiency.

All thermal loads were computed on a monthly basis and then the annual energy saving from space heating and hot water production were calculated. According to the Greek regulation, a six-month heating period from November to April was used for Heracleion (Zone A) and Athens (Zone B), and a seven-month heating period from October to April for Thessaloniki (Zone C) and Florina (Zone D), with an internal set point temperature of 20 °C and an air change rate for the building of 70 m3/h. Respectively, for the cooling period a five month period, from May to September, was assumed for Heracleion and Athens, and a four month period, from June to August, for Thessaloniki and Florina. Monthly space heating and cooling loads per floor surface area are presented for each location in Figs. 4 and 5 respectively. Hot water demand was calculated for the whole year for a capacity of 50 l/day per person at a temperature of 45 °C. The monthly loads per floor surface are presented for each location in Fig. 6.

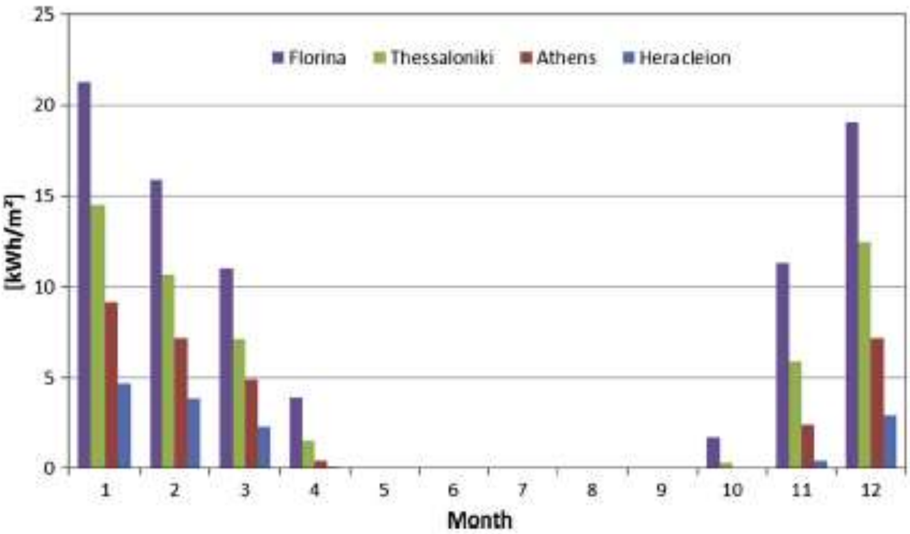


**Fig. 4.** Monthly space heating loads per city (kWh/m2).

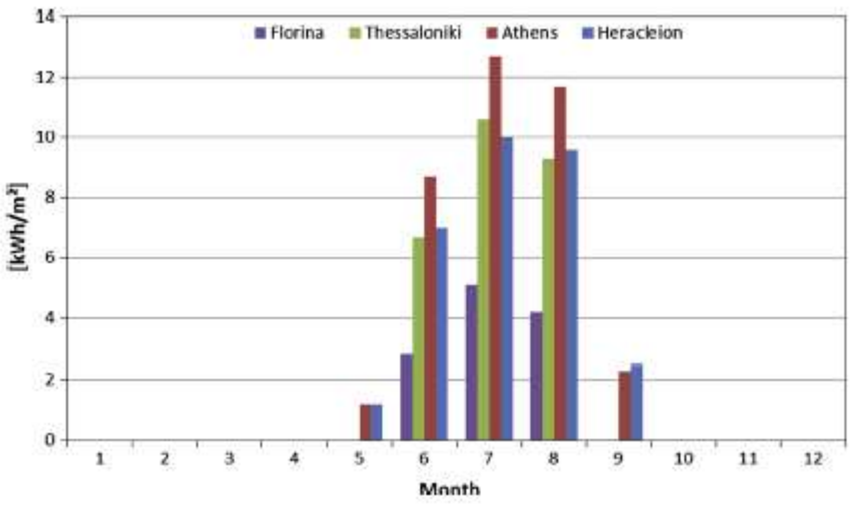


**Fig. 5.** Monthly cooling loads per city (kWh/m2).

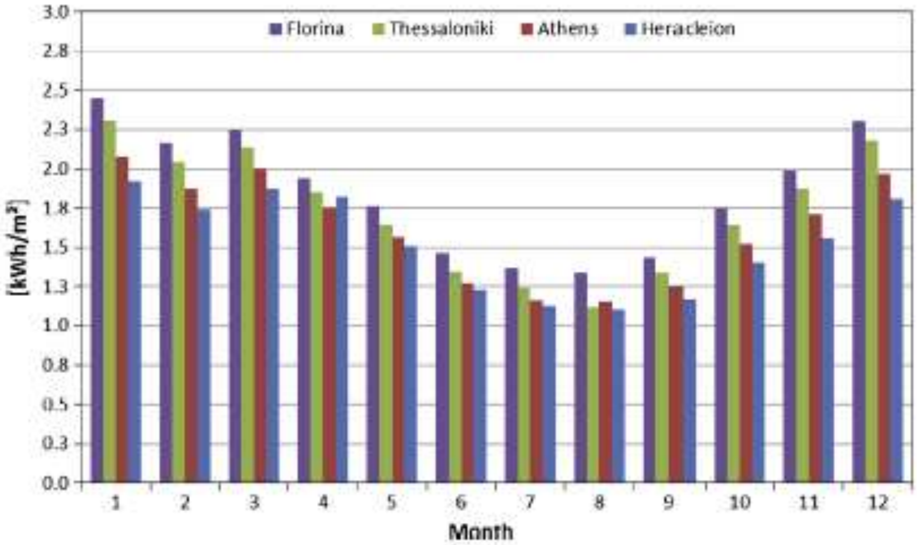


**Fig. 6.** Monthly domestic hot water loads per city (kWh/m2).

## 4- WEATHER DATA GATHERING

Collecting the solar data for Cairo –the project location, technical characteristics of the solar thermal system, Initial cost of the investigated solar combi systems (€) and technical characteristics of the photovoltaic system will be the first step, and then analyzing the data in order to have all the given for the decision making process.

**Table 1.** Daily solar radiation

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Daily radiation in kWh/m2/day | 3.18 | 4.30 | 5.60 | 6.68 | 7.39 | 8.01 | 7.93 | 7.36 | 6.34 | 4.93 | 3.73 | 2.96 |

**Table 2.**Technical characteristics of the solar thermal system.

| Collector type | Flat-plate, copper tube with copper foils |
|---|---|
| Glazing | Single sheet clear tempered glass (4 mm) |
| Selective coating characteristics | $\alpha = 0.94 \pm 0.02$ $\varepsilon = 0.05 \pm 0.02$ |
| Collector inclination | 45° |
| Collector area | 12–14–16–18–20–22–24–26 $m^2$ |
| $F_R U$ | 5 $W/m^2 K$ |
| $F_R(\tau\alpha)_n$ | 0.75 |
| Storage capacity | 750–1000–1250–1500–2000 l |
| Tank storage insulation | 100 mm Polyurethane foam |
| Solar loop heat exchanger area | 2.2–2.8–3.5–4.5–6 $m^2$ |

**Table 3.** Initial cost of the investigated solar combi systems (€).

| Storage tank (l) | Solar collector area ($m^2$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 |
| 750 | 4000 | 4300 | 4600 | 4900 | 5200 | 5500 | 5800 | 6100 |
| 1000 | 4400 | 4700 | 5000 | 5300 | 5600 | 5900 | 6200 | 6500 |
| 1250 | 4800 | 5100 | 5400 | 5700 | 6000 | 6300 | 6600 | 6900 |
| 1500 | 5300 | 5600 | 5900 | 6200 | 6500 | 6800 | 7100 | 7400 |
| 2000 | 5700 | 6000 | 6300 | 6600 | 6900 | 7200 | 7500 | 7800 |

**Table 4.** Technical characteristics of the photovoltaic system.

| Panels | Multicrystaline 235 $W_p$ |
|---|---|
| PV efficiency | 14.2% (1% degradation annually) |
| Nominal operating cell temperature | 45 °C |
| PV panel inclination | 35° |
| Installed capacity | 3–5–10 $kW_p$ |
| Inverter capacity | 3–5–10 kW |
| Inverter efficiency | 97% |

Using the data gathered in the previous section, some analysis will be done in order to determine the best PV panel inclination angle, and the best type that would suit the Egyptian context. Based on a paper that tested actual PV panels installed in Cairo for a whole year with different inclination angles (15 and 30 degrees) and different types of panels concluded that the 30 degree inclination and polycrystalline type is the optimum, based on Cairo's meteorological data. The most important data to be considered in this case is the energy consumption data because it has a direct impact on the amount of energy to be saved either through retrofit or to be generated by the renewable energy system. An average consumption monthly rates were detected as seen in figure 4 from the actual electricity bills of the case study building.

## 5. SOLAR ENERGY SYSTEMS POTENTIAL ESTIMATION

For the energy produced from the solar combi system, the widely available "f-chart" method (Duffie and Beckman, 2006; Brinkworth, 2001; Minnerly et al., 1991; Martinopoulos et al., 2013) was implemented in order to estimate the load covered by the different sized systems for each climatic zone. Furthermore, the impact of the storage tank size and of the total solar collector area was examined in order to find, not only the system with the optimal energy performance but all possible combinations in order to achieve at least a 50% solar coverage. For the electricity produced by the photovoltaic system the on-grid model of RETScreen was used (International, 2014). The energy produced (Ep) by the PV array is calculated using the following equation:

$$E_p = S n_p \bar{H}_t \tag{1}$$

S being the array area, np the average array efficiency and Ht the average solar radiation on the array. Energy produced by the array is then multiplied with loss factors regarding power conditioning and array shading losses in order to calculate the available energy. For the on grid model, no load is specified and the available electricity is estimated as the difference between the available energy and the inverter losses.

5.1. Renewable energy

In this case study, only one type of renewable energy is considered in order for the study to be able to cover all the aspects of this type. The chosen system will be solar photo-voltaic panels, in the following section the exact design and implementation steps will be discussed.

5.1.1. System design:

A. Design basic data:
• Location: Nasr City, Cairo, Egypt
• Global Horizontal irradiance GHI: annual average = 5.4 kWh/m2/day
• Building average consumption: 24 kW
• Maximum power needed: 12040 kWh during August

B. Panels basic data:
• The panels' orientation: panels will be installed facing south direction based on the solar data analysis provided previously.
• The panels' inclination angle: will be 30 degrees.
• Type of panels will be poly crystalline type because it generates the largest amount of energy in the Egyptian circumstances.
• The spacing between panels in order to avoid surplus shading of the panels on each other was calculated that if the tilting angle was 30 degrees, then a space of 60 cm must be between each row of panels and the one proceeding it.

C. Panel distribution:
After deciding the tilting angle, the orientation and the panel type comes the panel design phase. The figure 5 shows the proposed panel distribution including the maximum number of panels that could be installed on the building roof.

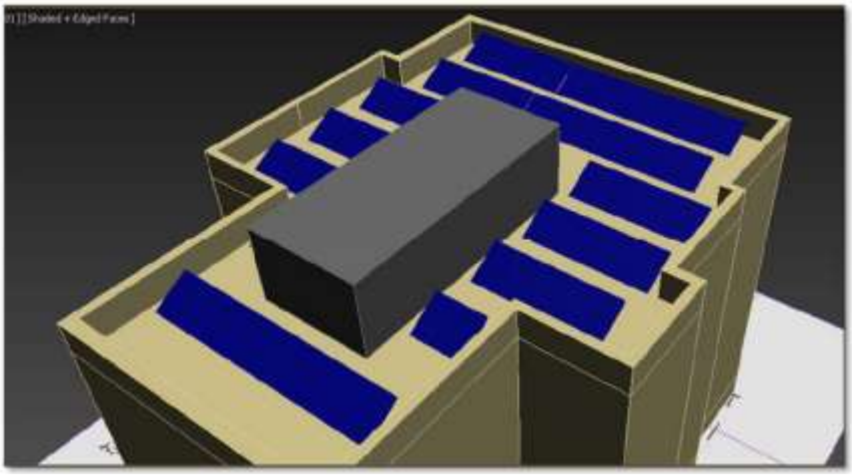

**Fig. 7.** PV panel distribution on building roof

## 6. RESULTS

With the implementation of the f-chart method for the 40 different sized solar combi systems, the influence of the storage tank and the total area of the solar collectors on the total thermal load and the NPV and DPBP were initially investigated in order to identify the system with the optimal energy performance. As becomes apparent from Fig. 8, the increase of solar collector area influences solar coverage more than the increase of storage tank capacity. It is important to note, that in all the examined cases, solar coverage exceeds 60% of the total thermal loads (space heating plus domestic hot water).

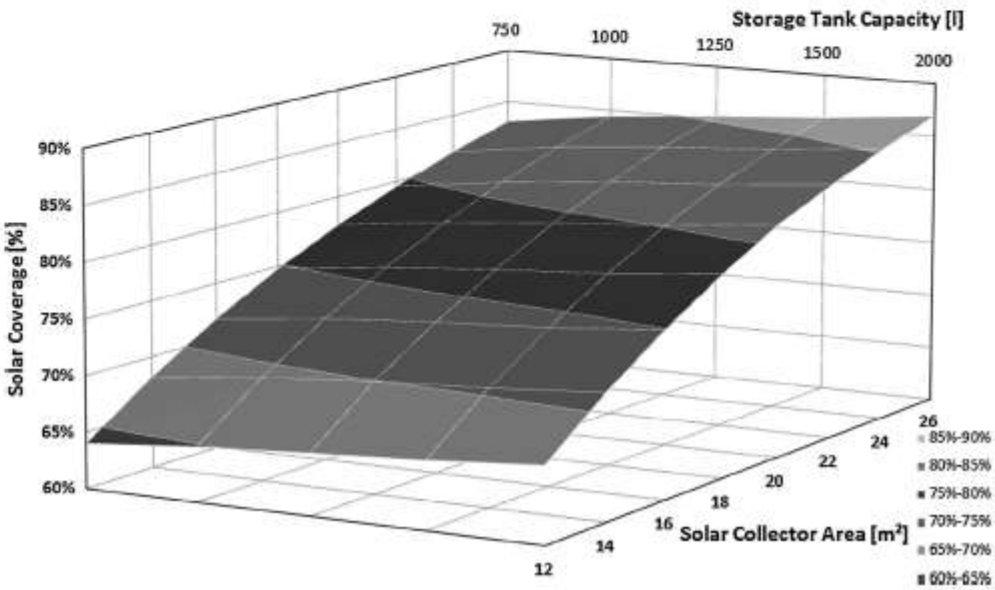


**Fig. 8.** Influence of collector area and storage tank capacity on the total solar coverage for systems installed in Athens.

From all the systems investigated it is assumed that the buildings are equipped with a system that provides annual solar coverage of at least 50% of the total thermal loads, which is a 24 m2/1000 l system for Florina, a 16 m2/750 l for Thessaloniki and a 12 m2/750 l system for Athens and Heracleion. The NPV cash flows and DPBP for the systems selected are presented in Fig. 9. The annual electricity production of the investigated photovoltaic systems is in all cases considerably higher than the average annual electricity consumption of 3750 kWh, and it ranges from 4.7 MWh in Florina (for a 3 kWp system) to more than 21.2 MWh in Heracleion (for a 10 kWp system). The different production and installed capacity per site is presented in Fig. 10. In all cases, as shown in Fig. 11, the systems provide a significant positive NPV cash flow which ranges between 8 and 13 times that of the initial cost of the system, and a payback period of between 4 and 6 years.

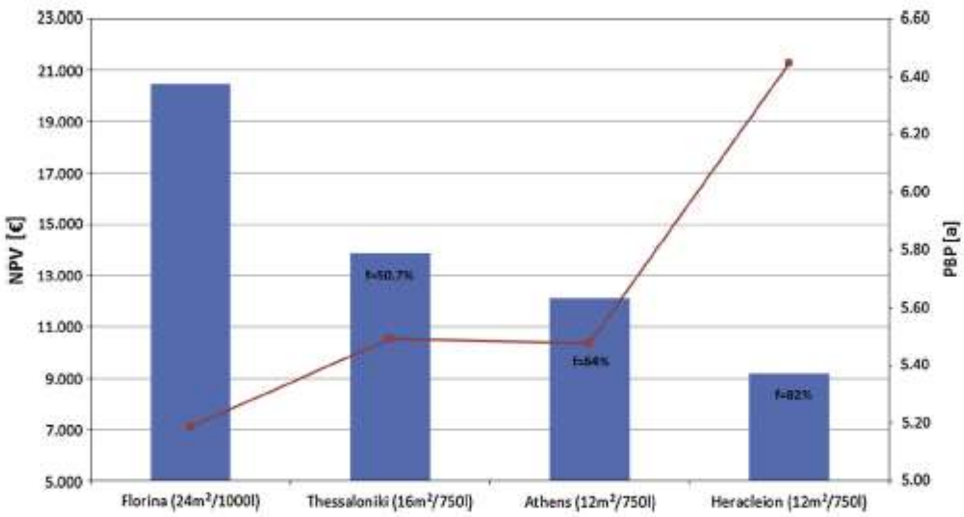


**Fig. 9.** NPV and DPBP of the most suitable solar combi system for each location.

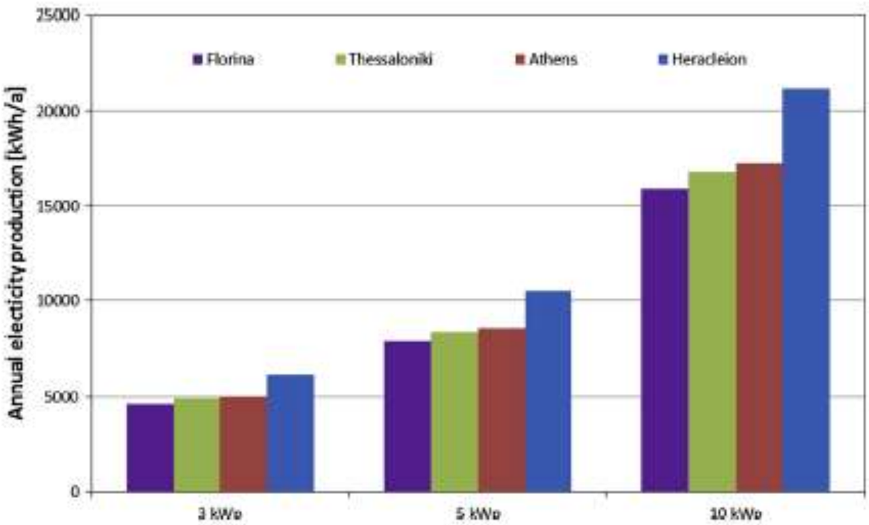


**Fig. 10.** Annual electricity production for the different PV systems in each location.

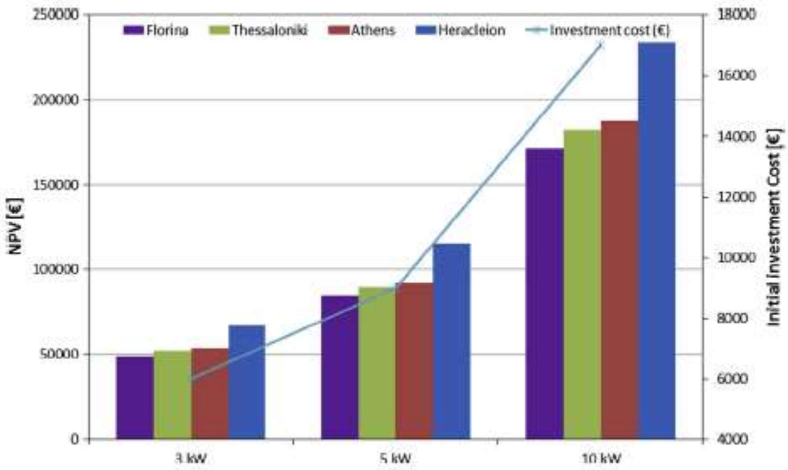


**Fig. 11.** NPV and Intital cost for the different PV systems in each location.

The total primary energy demand must be calculated in order to estimate the total solar coverage of the combined systems. The primary energy demand in each case is determined from the final energy use, by multiplying with the legislated factors (1.1 for fuel oil, 2.9 for electricity and 1.0 for solar) (NONEE 20701–3/2010, 2070).

For the PV system to be calculated, the amount of electricity resulted from the simulation is used (44,000 kWh). Knowing that every 1 kW power station generates 1800 kWh/year, then the building will need a 24 kW station (44,000/1800). As stated by the supplier, for each 1 kW power station 4 panels and a surface area of 10 m2 of plane roof is needed and it will cost 10,000 LE.

**Table 5.** PV system cost.

| Item | Quantity | Unit price | Description | Overall price |
|---|---|---|---|---|
| PV on-grid system (after retrofit) | 96 Panels | 10,000 LE/ 1 kW (24 kW needed) | Polycrystalline PV panels | 240,000 LE |

## 7. CONCLUSION

In this paper the investigation of solar potential regarding photovoltaic and solar thermal utilization in typical residential buildings was carried out in an effort to identify their impact towards nearly NZEBs. The methodology applied was based on steady state energy calculation, which may provide slightly less accurate results than dynamic simulations, but can be implemented quickly and efficiently for a variety of different building topologies. The use of a solar combi system for space and water heating, coupled with a small photovoltaic system can provide enough energy for a building to be though as a nearly NZEB. As the Energy Performance of Buildings Directive requires the use of renewable energy systems in buildings, consumer interest towards them is going to increase in the next few years. Especially, in view of the recast of the Directive which specifies that all buildings in EU should be nearly zero energy consumption buildings, thermal load coverage will be primarily achieved through an extensive use of solar energy systems that will contribute to the electricity, heating, cooling and domestic hot water requirements of the building.

Existing residential buildings in Egypt suffer from low insulation levels from which increases the energy consumed to reach the thermal comfort inside the building. A possible solution for this problem is to convert existing buildings to Net Zero-energy buildings. The study proposed a guideline to be followed to reach this result and implemented the guideline on a case study building in Cairo. The results of the study reveal that an existing residential building can be converted to a Net Zero-energy building using the proposed guideline. The cost analysis implemented in the study reveals the exact costs of both the retrofit actions –using materials existing in the market- and the PV panels' installation and it was found to be affordable.

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