Towards Net-Zero Neighborhoods in Greece

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Abstract

The paper discusses the installation of PV and solar thermal collectors on the available roof spaces, by applying heat pumps and energy efficiency standards in multi-apartment buildings, aiming to recommend measures towards net-zero neighborhoods. A real building is used varying the number of stories in the various Greek climate zones. Globally acknowledged standards such as EnerPHit are applied to investigate the potential of covering the electricity loads with PV. Besides, the choice of the heating and cooling generation system is investigated. Split units or heat pumps are used varying the COP and the design sink temperature to provide a complete overview of the energy performance. The results show that in a neighborhood with 9 buildings from 3- to 5-story buildings, the PV yield could cover 80% of the total required electricity for the year.

Keywords: Net-zero neighborhood, EnerPHit, multi-apartment buildings

1. Introduction

The need for self-production of the energy required in houses is getting more and more important in Europe. The net-zero energy goals are still not clearly defined. For example, an NZEB definition based on the type of balance (import/export, load/generation balance, or monthly net balance) is proposed (Sartori, Napolitano, and Voss 2012). Ochs, Dermentzis, and Ksiezyk (2017) highlighted the importance of considering other metrics than the mere energy balance, such as the load match factor and the PV self-consumption. In Mediterranean countries, the potential for using solar energy is very high. Besides, very good energy renovation standards such as EnerPHit (Zeno and Feist 2012) are well known to minimize building loads. De Masi, Gigante, and Vanoli (2021) proposed that a tradeoff between the thermal insulation and the installed power of renewable sources should be found. Feist (2014) suggested to use the footprint area for the specific PV electricity instead of the treated area of the building.

Papadopoulos (2016) discussed the development of regulations regarding energy standards in European countries. In a comparison between German and Greek energy regulations, the heating energy requirements were higher in Greece than in Germany since 1994 even though Berlin has almost four times higher heating degree days (HDD) than Athens. The final energy consumption in Greece increased by 7.1% from 1995 to 2011 and the residential total floor area by 16.5% (Papadopoulos 2016), meaning a reduction in the specific final energy consumption. There is a clear trend of U-value reduction over the past 40 years. Karkanias et al. (2010), in 2008 interviewed 17 persons from construction, research, and public sectors about the development of bioclimatic buildings in Greece. They concluded among others that the main barriers were the lack of adequate policy by the state, however in 2010 the a regulation on Energy Performance of Buildings (KENAK) was announced (E. G. Dascalaki et al. 2012) and revised in 2017 ("KENAK 2017. Greek Code of Energy Performance of Buildings" 2017).

Dascalaki et al. (2010) investigated a sample of 250 buildings from various areas in Greece to represent the Hellenic building stock. They found that buildings' U-values of walls, roofs, and windows, show a trend to decrease over time. In addition, the thermal energy consumption was the highest part of final energy consumption and it varied between 70 kWh/(m^2·yr) and 155 kWh/(m^2·yr) in residential buildings and 26 kWh/(m^2·yr) and 233 kWh/(m^2·yr) in non-residential buildings. The contribution of solar thermal collectors in domestic hot water production decreases the total electrical energy consumption by 27%-37% in single-family houses and 36%-57% in multi-family houses. Over 60% of the external walls do not reach the minimum U-value defined in the building codes. Space heating (SH) dominates the final energy consumption with 66% and 50.5% in residential and non-residential buildings, respectively, while the share for cooling is

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1% and 6.5%, correspondingly. However, space cooling (SC) may increase importance in Greek cities, especially in Athens due to the increase of the ambient temperature over the years and the island heat effect. Papakostas, Mavromatis, and Kyriakis (2010) calculated an increase in cooling demand in Athens by 26% between the decade 1983-1992 and 1993-2002.

This study aims to quantify the required combination of building renovation and on-site renewable sources in Greek neighborhoods towards net-zero energy. Furthermore, the impact of using split units or heat pumps is investigated aiming to provide a complete overview of possible SPF in various Greek cities.

2. Methodology

A real building that has been renovated is considered as a reference. It is modeled in PHPP (Feist 1998) such to account for varying number of floors, in different climatic conditions (10 cities), and different HVAC system and installed renewable sources. Furthermore, the obtained results are extrapolated to a typical neighborhood in Thessaloniki.

The building has been renovated according to EnerPHit standard (Zeno and Feist 2012) and it was modelled in PHPP (Feist 1998) by the Hellenic Passive House Institute. That building is chosen as a typical one having also an open space on the ground floor (often used for car parking called ‘piloti’), which is very common in multi-apartment buildings in Greek cities. Split units are considered to supply both space heating and cooling. It has to be noted that split units used for cooling is a very common system in Greece. But the use of spit units for space heating is not a favorable solution from the occupant’s point of view due to poor thermal comfort conditions in poor energy-performance buildings. However, this is not the case in a well-insulated building due to the high radiative indoor temperature since the internal surface of the opaque and transparent elements have high temperature due to low transmission losses of the insulated walls and good energy efficient windows. For the DHW preparation, either solar thermal collectors or electric water tank heaters are used, since both are common solutions in Greece. As an additional option, the use of air-source heat pumps to supply space heating and DHW is investigated (cooling can be also provided only if the existing radiators are changed to fan coils). The available roof space without significant shadings is fully covered with PV (in 0° inclination angle to install the maximum possible number of PV modules) and/or solar thermal.

Fig. 1 shows a typical neighborhood of a Greek city, in which the number of stories is quite different. Thus, as a next step, the number of stories as well as the location is varied in PHPP.

Besides, even though ‘net-metering’ is currently available in Greece, the part of PV electricity that is directly used is investigated with or without batteries. The following parameters are varied:

- The climatic conditions - 10 Greek cities
- The number of stories of the multi-apartment building - from two to eight stories
- Three HVAC systems:
    a) split units for SH and SC and solar thermal collectors (ST) for the DHW preparation (including an electric rod), the rest of the roof is covered with PV,
    b) air-source heat pump (HP) for SH, DHW and optionally SC (assuming an installation of fan coils, otherwise split units for SC), the roof is fully covered with PV and
    c) split units for SH and SC, and electric water heaters (with a tank) for the DHW preparation, the roof is fully covered with PV.
- Use of PV electricity: i) “net metering” currently available in Greece, ii) part of direct use of PV electricity without or iii) with batteries. For the share or directly used PV electricity, the “PVecon” tool is used (Ochs, Dermentzis, and Magni 2022).
- The energy performance of the split units and the heat pumps is investigated by varying: first the COP assuming a better product and second the sink temperature for supplying space heating. Four different efficiencies are considered namely ‘poor’, ‘moderate’, ‘good’ and ‘very good’, with a corresponding COP of 2.8, 3.3, 3.7, and 4.2 at 2 °C ambient temperature and 35 °C sink temperature. The sink

temperature is varied with a step of 5 K from 35 °C up to 45 °C in the case of split units and up to 60 °C in the case of HP.

Fig. 1: View of a neighborhood in Thessaloniki, Greece [from Google Earth] and a photo of the street view.

Fig. 2 presents climatic data of 10 cities from the coldest to the warmest. The maximum monthly temperature is similar in most of the cities except for the three coldest, however, the minimum monthly temperature is quite different from 2 °C in the coldest (Kastoria) to 12 °C in the warmest (Heraklion). Global radiation has a similar trend to the minimum monthly temperature with a range between 1525 to1838 kWh/(m^2 a).

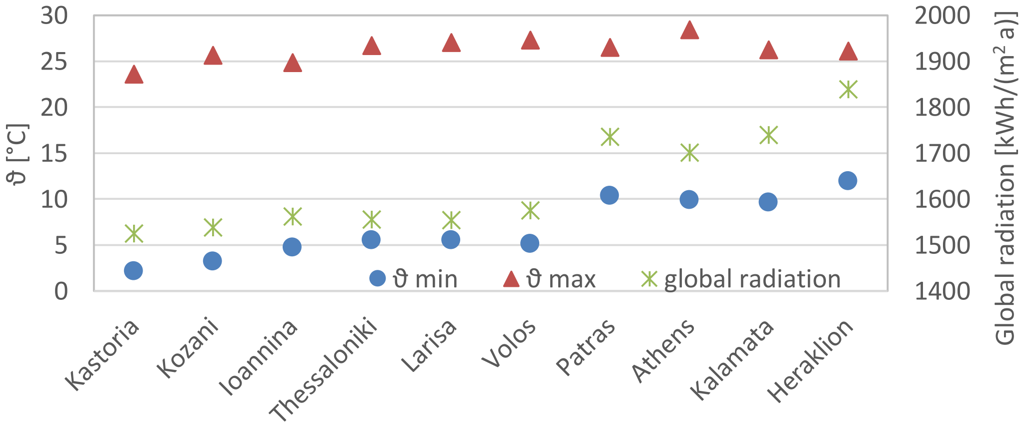

Fig. 2: Minimum and maximum monthly ambient temperature and the annual horizontal global radiation of the 10 climates (sorted from cold to warm)

In Tab. 1, the space heating and space cooling criteria to reach EnerPHit are presented as well as the calculated DHW demand and the household electricity by PHPP. The calculated number of persons in PHPP is approximately 3.6 persons per story. According to the EnerPHit standard the limit for SH is 20 kWh/(m^2 a) in the sixth colder climates and 15 kWh/(m^2 a) in the rest, while SC varies depending on each case up to a maximum of 21 kWh/(m^2 a). It is worth to be noted that the criteria to reach the Passive House standard are the same expect for the sixth colder climates in which the SH has to be 15 kWh/(m^2 a). The DHW demand varies from 11.4 to 13 kWh/(m^2 a) due to the different cold water temperatures.

Tab. 1: Space heating and cooling demands (limits according to EnerPHit standard) and DHW demand and household electricity based on PHPP.

Climate	SH demand	SC demand	DHW demand	Household electricity
	kWh/(m^2 a)			
Kastoria	20	15	13.0	23.9
Kozani			12.5	
Ioannina				
Thessaloniki		17	12.0	
Larisa		15		
Volos		16		
Patras	15	21	11.4	
Athens		17		
Kalamata		19		
Heraklion		20		

In order to achieve the required SH demand in each climate, the U-values vary quite significantly. Tab. 2 shows the applied values for a 3-story building located in different cities. In the coldest climate, the U-values of the insulated opaque elements are even below 0.1 W/(m^2 K) similar to the central European climate. In the rest cold climates (from Kozani to Volos), located in the North and in the middle of the country, the required U-values are between 0.12 and 0.18 W/(m^2 K). In the warmest climates, located in the southern part (such as Athens), the U-values are higher with a max of 0.47 W/(m^2 K) in Heraklion.

Tab. 2: U-values of the opaque and the transparent (as well as g-values) elements for a renovated building with 3 stories

Climate	wall	roof	slab ambient	slab ground	windows	g-value
	W/(m^2 K)					[-]
Kastoria	0.08	0.09	0.08	0.53	0.90	0.54
Kozani	0.12	0.12	0.12	0.53		
Ioannina	0.13	0.13	0.13	0.53		
Thessaloniki	0.17	0.18	0.17	0.53		
Larisa	0.17	0.18	0.17	0.53		
Volos	0.15	0.16	0.16	0.53		
Patras	0.28	0.31	0.31	0.54		
Athens	0.28	0.15	0.30	0.54		0.37
Kalamata	0.26	0.28	0.27	0.53		0.54
Heraklion	0.42	0.46	0.47	0.54		

3. Results and discussion

Fig 3 shows the influence of the climate on the SPF of the heat pump used for space heating and the PV yield. Presenting the climates from the colder to the warmer. It is observed that the same heat pump has better performance in south Greece from 22% (Patras) up to 32% (Heraklion) compared to the cold climate of Kastoria. The PV yield follows a similar trend but with lower values e.g., the highest increase is 20%.

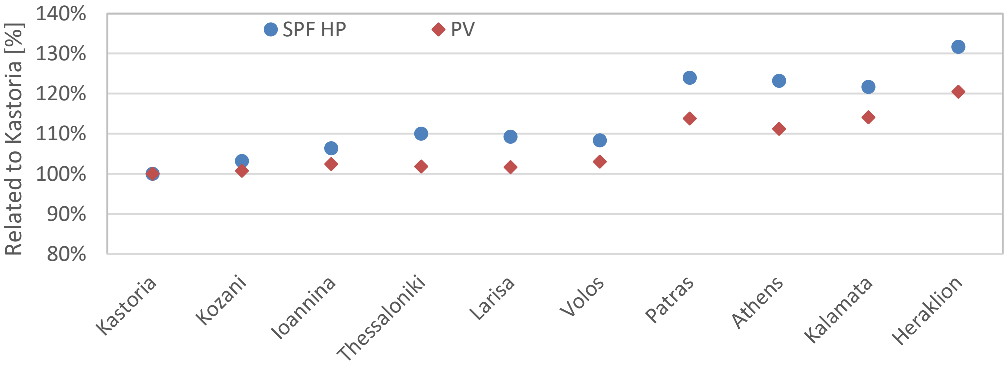

Fig. 3: Influence of the climate (10 Greek cities from cold to warm climate) on the SPF of the split units and the PV yield

A complete overview of the SPF of a heat pump used for space heating in four representative climates of Greece is presented in Fig. 4. It is observed that the choice of the heat pump has a similar impact on the SPF as the sink temperature. The latter depends on the heat emission and distribution system, the well-dimensioning/sizing of the HP, and the proper commissioning and operation (control) of the system. For example, in Thessaloniki, a poor HP that operates with a low sink temperature e.g., 45 °C leads to an SPF of 2.1, which is equal to the SPF for the case of a very good HP with a high sink temperature such as 60 °C. The choice of the HP based on its efficiency (i.e., COP) can have an impact on the electric consumption of up to 21%, e.g., in Kastoria the SPF increases from 1.6 to 2.1 (operation at 55 °C). An HP in Athens that operates at 50 °C instead of 60 °C results in 16% electricity savings and at 35 °C (by using fan coils) results in 42% or in absolute 3.1 kWh/(m^2 a) of electricity savings.

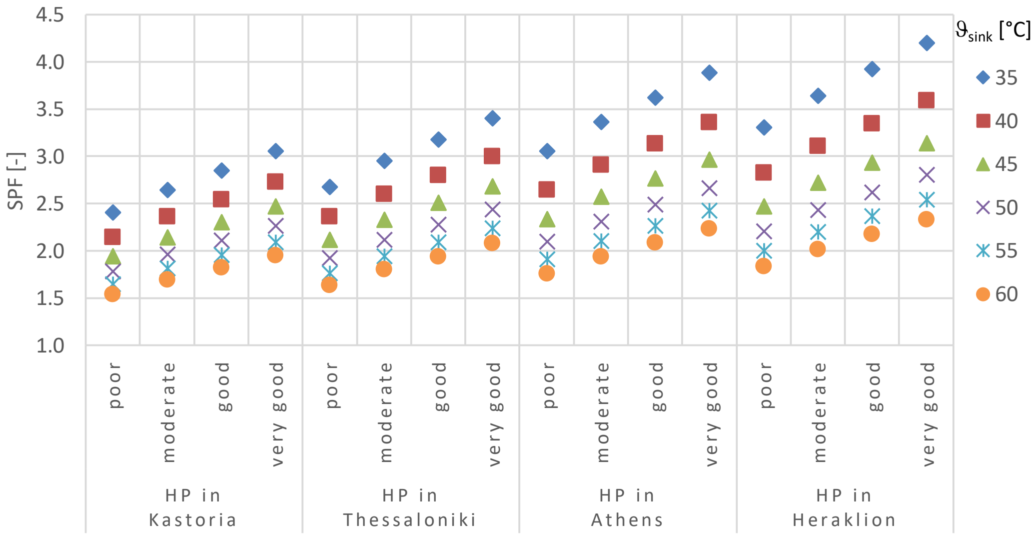

Fig. 4: Overview of the system performance factor (SPF) varying the design sink temperature, the efficiency of the heat pump, and the climate.

In Fig 5, the ratio of PV electricity and building consumption included (top) or excluding (bottom) the household electricity is presented varying the climate and the number of stories. By excluding household electricity from the balance, NZEB is possible in all climates when the building consists of a maximum of six stories. The climate influences the results; however, different measures should be applied in each climate to reach the standard (see Tab. 2). For example, the insulation thickness of the wall is 35 cm in Kastoria and six cm in Heraklion. Thus, the implementation of the building standard varies significantly, and the target of NZEB is easier to be reached in warm than cold climates due to higher SPF and PV yield that compensates for the increased cooling loads. It has to be noted that when the household electricity (23.9 kWh/(m^2 a)) is also considered in the balance, NZEB can be reached with a maximum of a 3-story building.

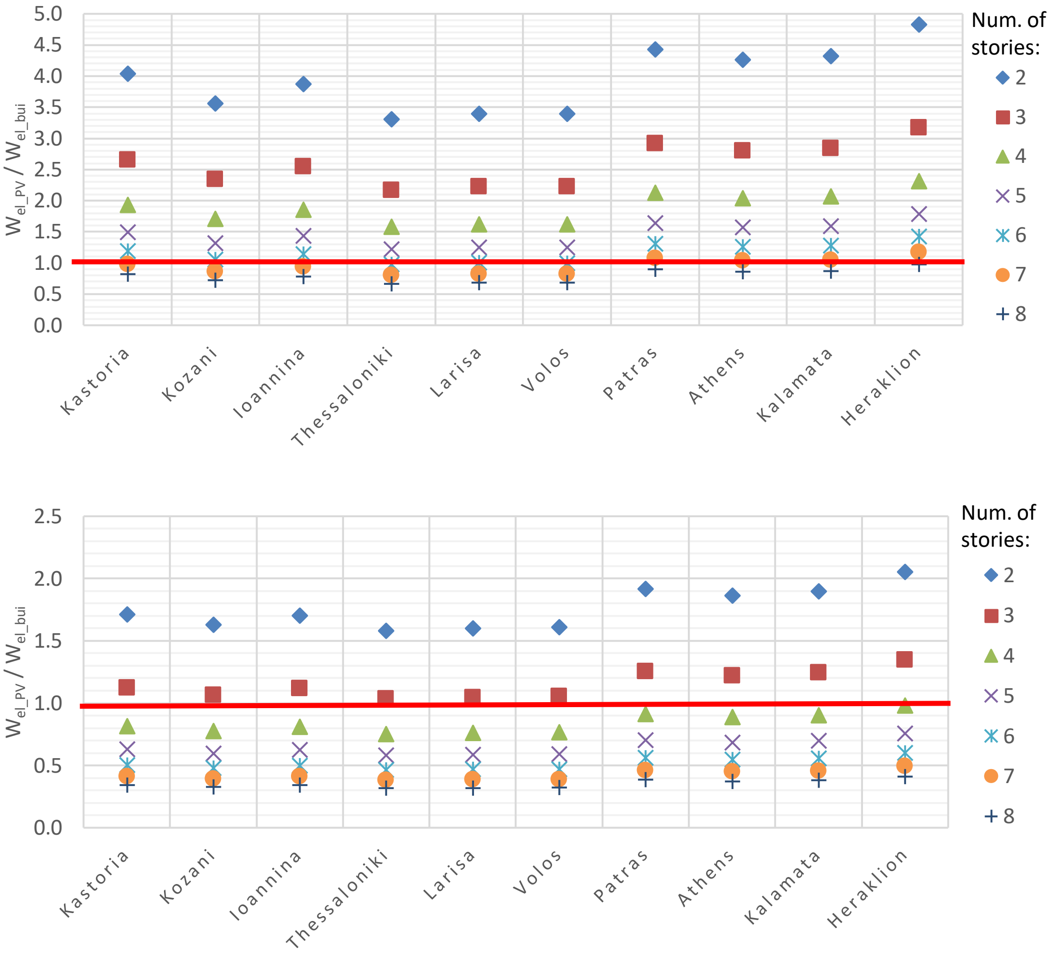

Fig. 5: Load factor considering net metering i.e., the ratio of PV electricity and building consumption over a year, depending on the climate and the number of stories including (top) or excluding (bottom) household electricity

The results are applied in a neighborhood in Thessaloniki by varying the number of stories of each building. Tab. 3 shows the influence of using solar thermal for DHW rather than electric water heaters and PV. As can be seen, even if all buildings are renovated according to very good building standards and the roof space is covered with renewable sources, the neighborhood cannot be net-zero energy since the PV production is 20% less than the electricity needed. The latter becomes 30% when the roof is fully covered with PV and electric water heaters are used for DHW (i.e., no solar thermal collectors). The results highlight that a reduction of heating demands is a priority in energy policies so that the on-site renewable sources can cover a significant part of the electricity demand towards the target of net-zero neighborhoods. PV in the façade would be also an additional option however due to very dense building areas, the shadings can be an obstacle.

Tab. 3: Ratio of PV yield and electricity demand of a neighborhood in Thessaloniki once with using solar thermal to cover the DHW demand and once without solar thermal (i.e., roof fully covered with PV)

Num. of stories	**Num. of buildings**	**W_{el_PV} / W_{el_bui} with solar thermal**	**W_{el_PV} / W_{el_bui} without solar thermal**
3	5	1.03	0.87
4	1	0.75	0.66
5	3	0.58	0.53
neighbourhood:	**9**	**0.80**	**0.70**

The annual remaining electricity in the neighborhood that cannot be covered by on-site renewable sources is demonstrated in Fig. 6, varying the system used for space heating and DHW, as well as the efficiency of the system and the sink temperature. In the case of split units, the sink temperature is considered to vary from 35 to 45 °C, while in the case of an HP from 35 to 60 °C, assuming using fan coils (35 up to 50 °C) or new radiators (45 up to 55 °C) or existing (or even adding some more) radiators (55 up to 60 °C). The choice of letting the electric water heaters for the DHW preparation and covering the roof with only PV (without the use of solar thermal collectors) requires almost double electricity from the grid compared to the case with ST. The use of HP for SH and DHW could lead to less required electricity from the grid, however, proper dimensioning and a choice of an HP with rather high COP are required. This is similar to the findings from an Austrian case study (Ochs, Dermentzis, and Feist 2014). Typically, often the more complex the system is, the higher the possibility for maloperation such that the HP operates at the same temperature for SH as for the DHW (Dermentzis, Ochs, and Franzoi 2021). The use of the split units for heating and cooling combined with ST for DHW are totally independent and well-established systems reducing the risk of more inefficient operation than designed.

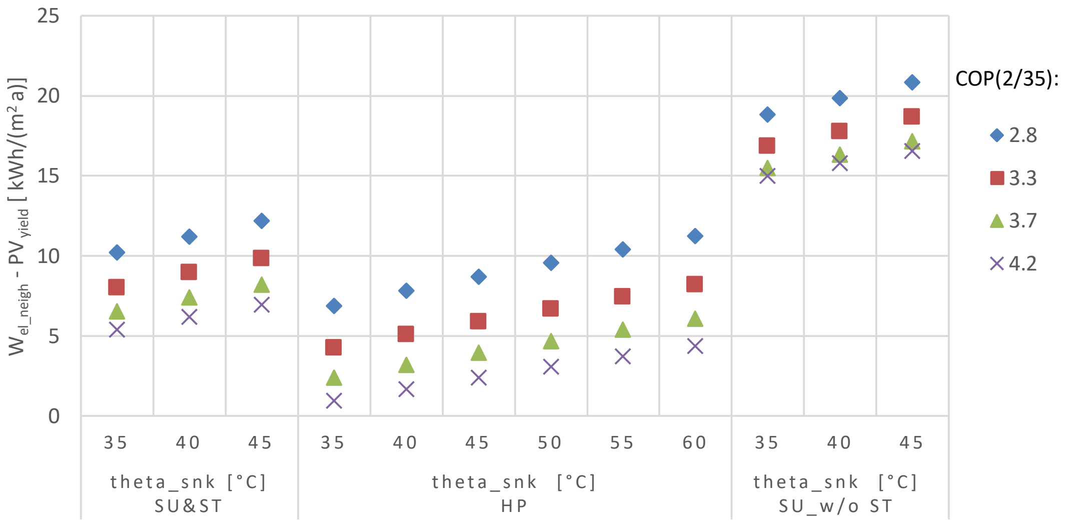

Fig. 6: Influence of the system and its performance on the final (site) energy for the neighborhood in Thessaloniki.

The annual electricity balance between PV production and electric consumption (i.e., ‘net metering’) that assumes the grid as ideal storage, can be misleading since the direct use of PV electricity in the building is significantly lower. Fig. 7 demonstrates the monthly electricity consumption dedicated to SH, DHW, auxiliaries, and household electricity, and the PV yield as well as the directly used electricity with or without battery installation of the 3-story building in Thessaloniki. The building is an NZEB with a ratio of 1.03 (PV yield divided by electricity consumption), however, in the winter months, the PV cannot even cover only the household electricity, resulting in high electricity demand in these months and overproduction in summer months. This need for electricity from the grid in the winter months will be significantly higher if other building standards are applied. This indicates the need for effective building energy renovations and even the need for seasonal storage. The part of the electricity consumption that is directly covered by the PV is calculated to be 0.37 in case of no batteries and 0.50 in the case with batteries. The use of batteries increases the share of direct PV electricity usage by 21%.

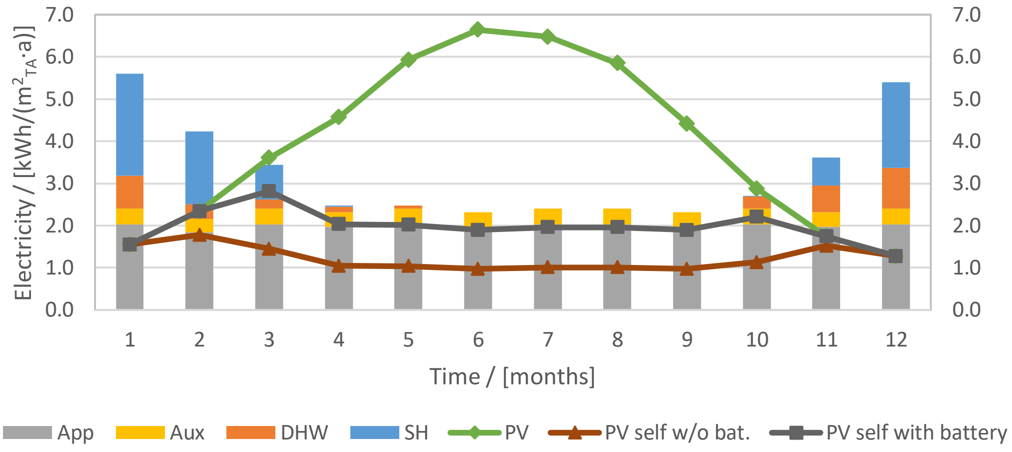

Fig. 7: Monthly electricity consumption for each application (i.e. SH, DHW, aux, and appliances) and monthly PV yield as well as the share of direct use of PV electricity with and without batteries for the 3-story building in Thessaloniki. Remark: cooling is excluded since it is not available in the current version of the PVecon tool.

New constructions consist of even more floors than the existing ones, for example, a new building in this neighborhood consists of 7 stories. This is an advantage from the space heating demand point of view due to compactness (volume/surface area). However, the remaining area for on-site renewable sources is the same, thus, other renewable sources have to be used. This increases the necessity of building new high-performance buildings and renovating the old ones with as sufficient measures as possible. Similarly, Papadopoulos et al., (2016) concluded about the real need for deep renovation of the building stock.

4. Conclusions

The study was performed to investigate the potential of applying EnerPHit standards in multi-family buildings varying the number of stories and including PV towards net-zero energy neighborhoods in Greece. The results show that PV can cover on an annual balance the electricity required for heating, cooling, DHW, and auxiliaries (excluding households) if the building is up to 6 stories in Greek climates. However, NZEB is possible up to a maximum of 3 stories when household electricity consumption is included in the balance, although the latter is not foreseen by national regulations.

The difference in climate in Greece does not have a significant influence on reaching NZEB levels, when the EnerPHit standard is applied. However, reaching the standards is much easier in the southern compared to northern climate; in the warmest climate, the required U-value of the wall is 0.42 W/(m^2 K) whilst in the coldest 0.08 W/(m^2 K); the latter figure might be challenging to achieve in practice.

The increased number of stories and also the increased compactness reduces the required measures to achieve high-performance energy standards, and at the same time, whilst the available roof space for PVs remains the same making the target of NZEB more difficult. Therefore, the implementation of a thermally well protected envelope is very important to reduce the required loads to the minimum. The choice of the heating generation system plays a major role and especially, solar thermal collectors are favorable from the energy point of view for the DHW preparation. In case of renovation, the system for DHW should be retrofitted, too and electric water heaters should be avoided even when combined with PV. Air-source HPs for supplying space heating and DHW (optional cooling, too – if fan coils are installed) combined with PVs have a potential for the highest efficiency. However, commissioning, control strategy, and sizing of the heat emission system are very important to operate the system with the lowest possible sink temperature resulting in high SPF up to 3.4 in Thessaloniki and 3.9 in Athens.

The results can be used for making policy about ways to reduce the on-site electricity consumption considering PV and solar thermal, prioritizing deep renovation concepts.

Future work should include also an economic analysis to reach the standards in several climates considering the heat and cool generation systems as well as the renewable sources.

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